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The University of Queensland Surat Deep Aquifer Appraisal Project (UQ-SDAAP)

Scoping study for material carbon abatement via carbon capture and storage

Supplementary Detailed Report

Integrated facies analysis of the Precipice Sandstone and Evergreen Formation in the Surat Basin

30 April 2019

Authors

Dr Andrew La Croix, The University of Queensland
Mr Jiahao Wang, The University of Queensland
Prof Jim Underschultz, The University of Queensland

Acknowledgements

This working document was prepared for The University of Queensland Surat Deep Aquifer Appraisal Project (UQ-SDAAP), a 3-year, $5.5 million project funded by the Australian Government through the Carbon Capture and Storage Research Development and Demonstration (CCS RD&D) programme, by Coal 21, and The University of Queensland.

Citation

La Croix A, Wang J & Underschultz J (2019*), Integrated facies analysis of the Precipice Sandstone and Evergreen Formation in the Surat Basin*, The University of Queensland Surat Deep Aquifer Appraisal Project – Supplementary Detailed Report, The University of Queensland.

Referenced throughout the UQ-SDAAP reports as **La Croix et al. 2019a.**

Publication details

ISBN: 978-1-74272-246-7

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1. Executive summary

Nine wells with significant sections of core from the Precipice Sandstone and Evergreen Formation were examined for their sedimentological and ichnological characteristics.

These were, in alphabetic order:

1. Chinchilla 4,
2. Condabri MB9-H,
3. Kenya East GW7,
4. Moonie 34,
5. Reedy Creek MB3-H,
6. Roma 8,
7. Taroom 17,
8. West Wandoan 1,
9. Woleebee Creek GW4.

From analysis of over 2000 m of cumulative section, 19 distinct depositional facies were identified that range from 0.11 m to 11.56 m thick.

The facies are grouped into five main facies associations, corresponding to:

1) braid plain,
2) lower delta plain,
3) delta lobe,
4) tidal flats, and
5) shoreface.

These facies and facies associations were used to construct the sequence stratigraphic framework by identifying depositional hiatuses.

They were also used as a primary training input for neural network log facies prediction, where the classifiers were utilised in petrophysical property calibration and to control the distribution of reservoir properties in static reservoir models.

2. Introduction

2.1 Purpose

The purpose of this report is to document the sedimentary facies characteristics of the Precipice Sandstone and Evergreen Formation of the Surat Basin Australia. These formations comprise the main prospective reservoir and seal intervals being investigated for their carbon dioxide (CO_2) storage potential. The primary task of the geology and geophysics team was to build several robust static geological reservoir models. This necessitated an understanding of the geology and groundwater flow units. To this end, available drill core data from the relevant intervals from across the basin was examined in detail from a sedimentological, ichnological and stratigraphic perspective. The methodology is to make palaeo-environmental interpretations of the strata that aid sequence stratigraphic correlations across the basin. These can then be used to map the distribution of geobodies in the subsurface and populate them with rock properties (e.g. porosity and permeability). This forms the basis of subsequent simulation of dynamic models that forecast the injection and migration of CO_2 and the implications for associated changes in formation pressure and water chemistry.

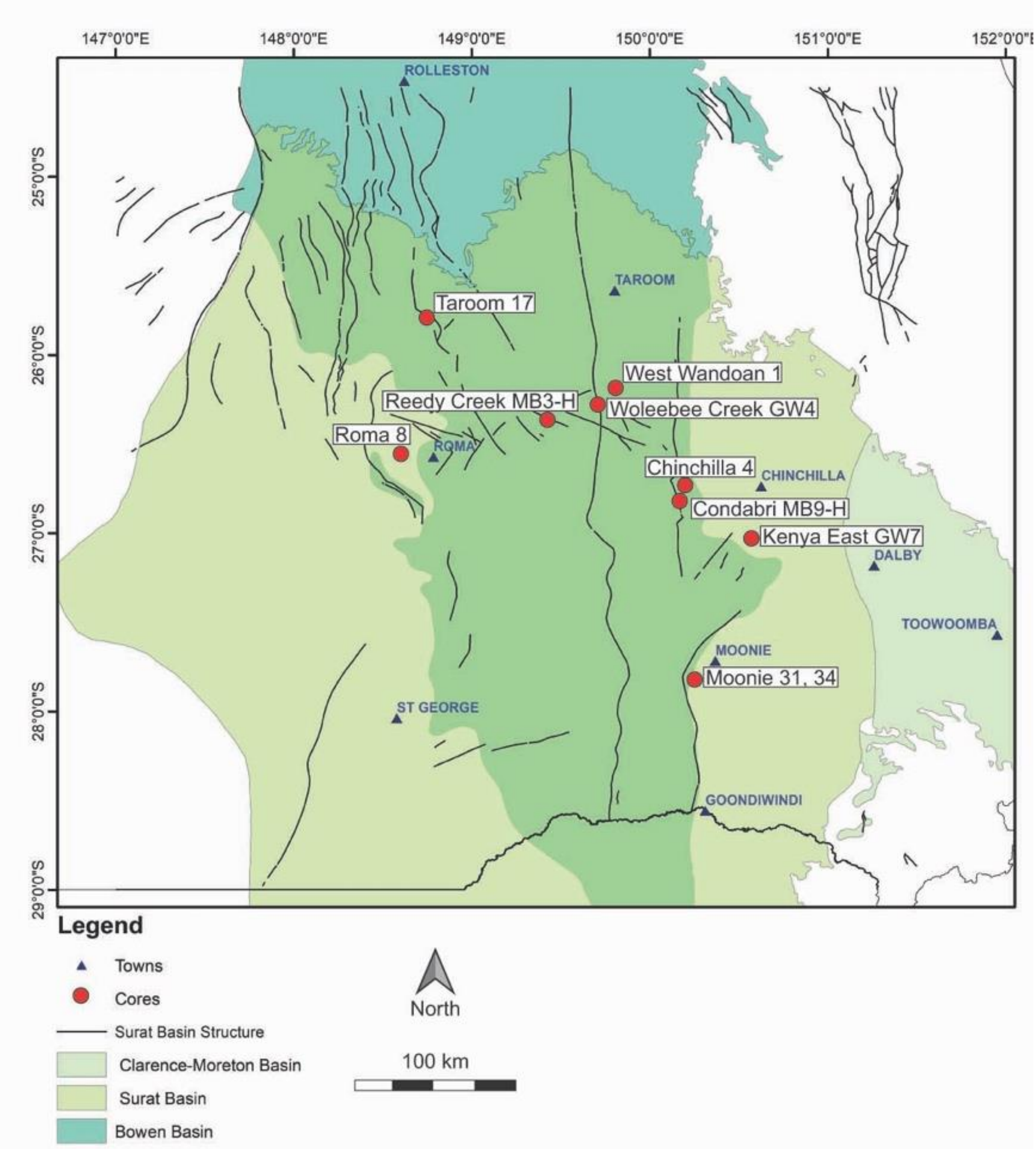
2.2 Background

Sedimentary facies from nine cored wells in the Surat Basin were classified according to their textural, sedimentological, and ichnological characteristics (Figure 1). These wells were selected, as they contained significant lengths of cored interval in the stratigraphic section of interest. Other wells may also have core, however, the limited extent of the cored interval in the stratigraphic section of interest limited their value for the purpose of this study. Textural observations include lithology, grain size, grain sorting, and roundness. Sedimentological data such as bedding style, physical sedimentary structures, cementation and accessory aspects were also recorded. Finally, information about the ichnological aspects of the sedimentary rock were recorded such as ichnogenera identification, trace fossil size, diversity, bioturbation intensity using the BI-scale (Taylor & Goldring 1993), and the distribution characteristics of burrowing between beds. In concert this data was used to make paleoenvironmental interpretations of the strata using process-response inferences following the methods and philosophy outlined in Middleton (1978) and Dalrymple (2010).

Following a classification of facies approach, the units were organised into groups of facies that occur together and are considered to be genetically or environmentally related (c.f. Dalrymple 2010). Facies associations are larger scale sedimentary packages that are interpreted to represent entire depositional environments (i.e. lower delta plain, channel complex, etc.). This is in contrast to facies-scale packages that are the result of distinct depositional processes occurring at the sub-environment scale (i.e. mouth bar, interdistributary bay, etc.). The recurrence of facies in facies associations was statistically confirmed using the Markov Chain approach (Miall 1973; Powers & Easterling 1982; Wells 1989), the results of which are contained in La Croix et al. 2019c.

In this report, each sedimentary facies is described in detail and an interpretation is provided in terms of the formative depositional processes and environments that represent that facies. Facies association descriptions and interpretations then follow, and all the results are summarised in a set of tables. Finally, individual cored intervals for the Precipice Sandstone and Evergreen Formation are documented from the base (bottom) up, showing how facies and facies associations are distributed vertically through the section.

Figure 1 The location of cored wells within the Surat Basin that were logged in detail as part of this study. A total of nine wells were examined, mostly occurring within the northern, north-eastern and north-western parts of the basin.



3. Results

3.1 Sedimentary facies

3.1.1 Facies G1: Interbedded conglomerate and sandstone (>30% granules and coarser)

Facies G1 consists of interbedded conglomerate and sandstone that has an average thickness of 0.77 m (mean=0.8 m, max=4.6 m; Appendix A; Figure 2). Sand is poorly sorted and ranges from medium to very coarse grained (0.25-2 mm), whereas conglomerate clasts vary from granules to pebbles (2-50 mm). Basal contacts are generally sharp or scouring and the upper contacts can be sharp or transitional. The facies is most commonly structureless, but sometimes maintains a crudely laminated appearance. There are no accessory components to the facies. Facies G1 most commonly overlies Facies S1, and less commonly Facies S2 or G2. The overlying facies are most commonly Facies S1 or S2 when no stratigraphic breaks occur.

Biogenic structures are absent from Facies G1, with BI 0 in both the sand matrix and coarse-grained clasts.

The stratigraphic occurrence of Facies G1, in combination with the coarse grain size and lack of well-formed bedding or physical sedimentary structures, suggests that it was deposited under high flow velocities with abundant sediment supply. In this context, the unit is interpreted to represent channel-lag deposits occurring at the base of braided fluvial channels.

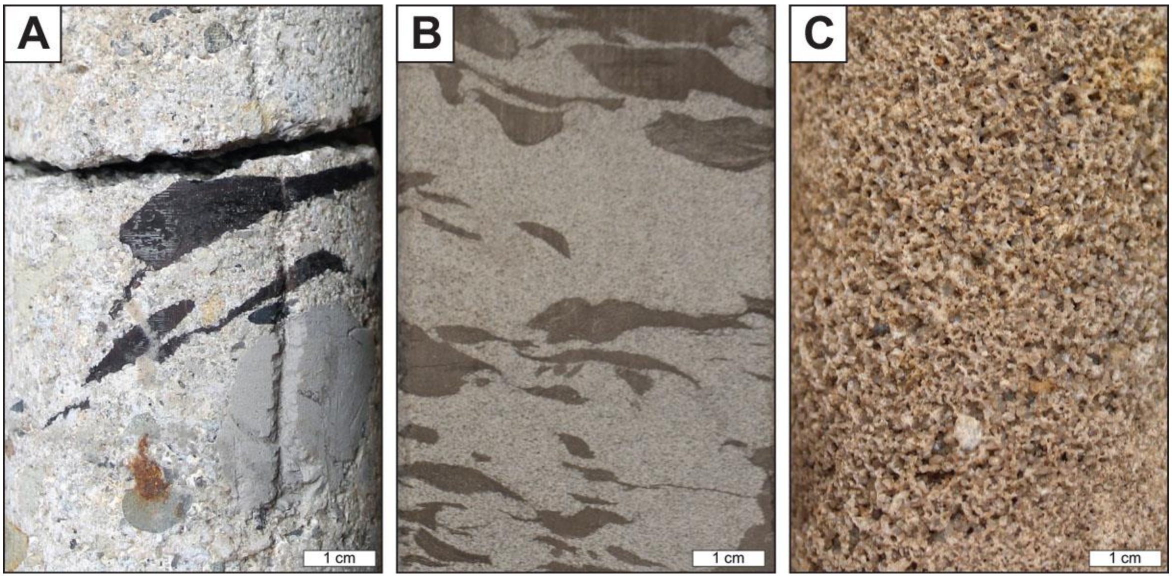
3.1.2 Facies G2: Mud-clast breccia (>30% granules and coarser)

Facies G2 comprises mud-clast breccia with an average thickness of 0.65 m (min=0.17 m, max=3.42 m; Appendix A; Figure 2). Sand is poorly sorted and varies from medium to very coarse grained (0.25-2 mm), whereas mud clasts range between granules and pebbles (2-50 mm). Basal contacts are sharp and scouring whereas the upper contacts are usually transitional. The facies is mostly structureless with a rare diffuse laminated appearance. No accessory components are common. Facies G2 usually overlies Facies S2 and seldom Facies S1, and is overlain by Facies S2.

Biogenic structures are absent from Facies G2; both sand matrix and coarse-grained components display BI 0.

In context, the occurrence of Facies G2 combined with the sandy matrix and angular mud clasts, shows that sediment transport of the clasts was for short distances and deposition occurred rapidly with abundant sediment supply. As a result, the facies is interpreted to have either been deposited at the base of fluvial channels or, more likely, as the channel-bank collapses due to undercutting of fluvial or distributary channels.

Figure 2 Core photographs of the facies that comprise Facies Association 1. (A) Facies G1 from Chinchilla 4, 1063.91 m. (B) Facies G2 from Kenya East GW7, 1152.6 m. (C) Facies S1 from Chinchilla 4, 1219.7 m.



3.1.3 Facies S1: Coarse grained planar-tabular to trough cross stratified sandstone (>90% sand)

Facies S1 consists of planar-tabular to trough cross stratified sandstone. The thickness of the unit varies from 0.2-77.2 m, with a mean of 11.55 m (Appendix A; Figure 2). Individual bedsets range from 0.3-0.8 m. The sand is poorly sorted, varying from medium to very-coarse grained (0.25-2 mm). The basal contacts are sharp and/or scouring in nature, whereas the upper contact is most commonly gradational. Physical structures include planar tabular cross bedding, trough cross bedding, and rare current ripple lamination at the tops of units. Rare accessories include rip-up clasts, scattered pebbles, and pebble lags. Facies S1 overlies Facies G1, G2, S2, S3, S4, SM1, and SM2 and is overlain by Facies G1, G2, S2, S3, S4, SM1, and SM2.

Biogenic structures are absent from Facies S1 (BI 0).

The predominance of medium to thick bedded, tabular and trough cross stratification indicates deposition by quasi-steady unidirectional currents. The stratigraphic context of Facies S1, in close relationship to channel-bank collapse and channel lag deposits and the overall lack of bioturbation, suggests deposition in energetic, fresh water, with abundant sediment supply at relatively high depositional gradients. This is consistent with a braided river to braid-delta interpretation for facies S1.

3.1.4 Facies S2: Planar-tabular cross stratified grading into current ripple laminated sandstone (>90% sand)

Facies S2 is composed of planar-tabular cross stratified sandstone that grades upward into current ripple laminated sandstone. The facies ranges from 0.1-18.7 m thick, with a mean thickness of 3.5 m (Appendix A; Figure 3). Cross-sets vary from 0.2-0.5 m. The sand component is generally moderate to well sorted, ranging from very fine to fine-grained (0.08-0.18 mm). Bottom contacts are sharp and commonly erosive; the upper contacts are mostly gradational. Physical sedimentary structures consist of planar tabular cross bedding, current ripple lamination, and less common, combined flow ripple lamination. Accessories are not common, but when present include carbonaceous detritus, rip up clasts, pebbles, and pebble lags. Facies S2 overlies Facies S1, S3, S4, M1, M2, M3, and O2 and is overlain by Facies S1, S3, S4, M1, M2, M3 and O2.

Biogenic structures are very rare in Facies S2, typically occurring near the top of the unit. Biotubation intensity ranges from BI 0-BI 1 and burrowing has a sporadic distribution. Trace fossils observed include interpreted freshwater or terrestrial deposit feeding forms such as *Planolites* and *Taenidium.*

Planar-tabular cross stratification is indicative of migrating dunes in quasi-steady unidirectional currents in water. The presence of a fining upward profile to the facies capped with current or combined flow ripple lamination is evidence for ripple-scale bedforms produced from waning flow conditions. The overall low and sporadically distributed ichnofauna produced by presumed freshwater organisms suggests an environment with well oxygenated, fresh water conditions. Rootlets and carbonaceous detritus show that the depositional setting was also suitable for colonisation by land plants. Taken in context these pieces of evidence support a meandering fluvial or distributary channel depositional interpretation for Facies S2.

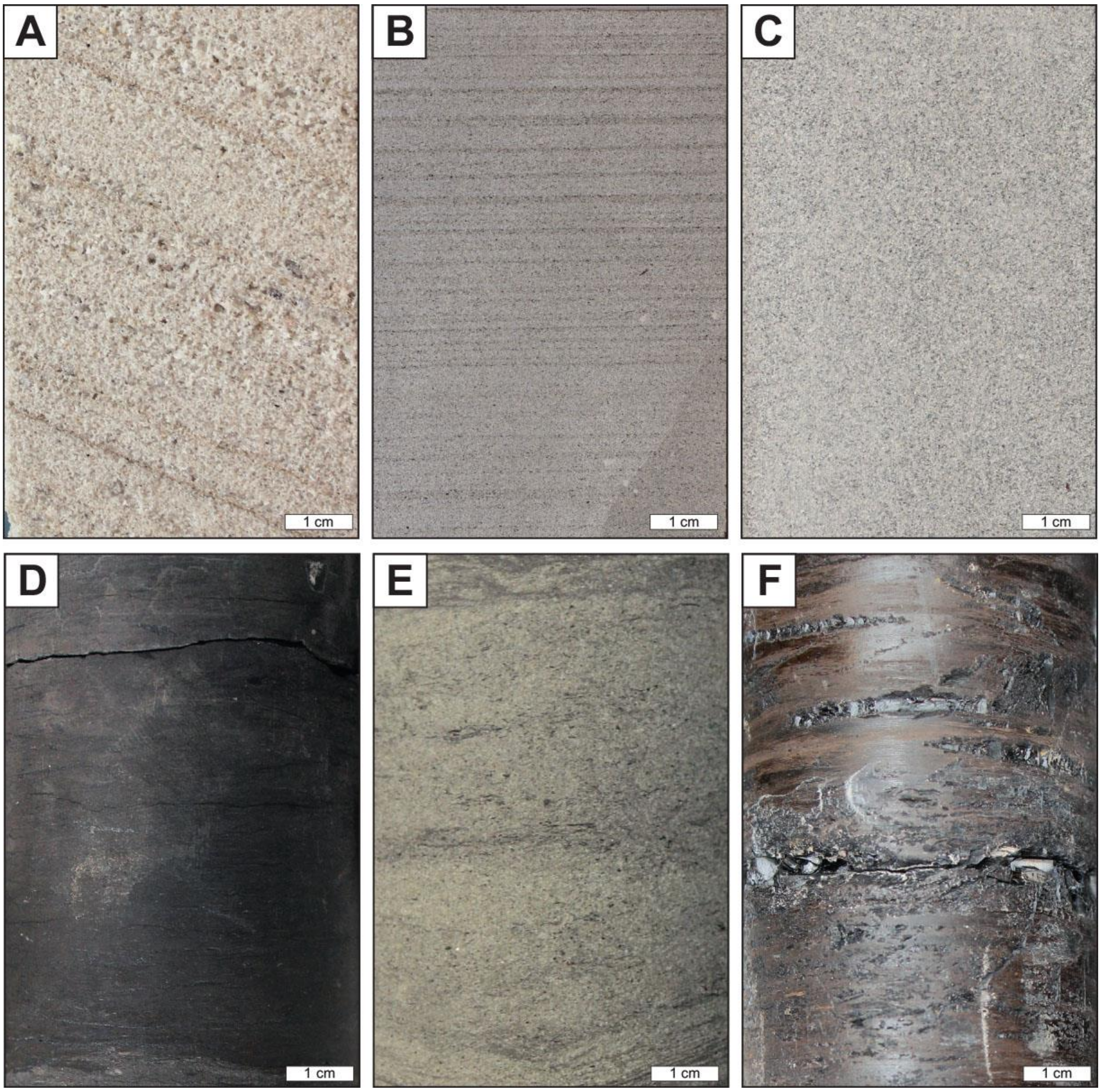
3.1.5 Facies S3: Wave to combined-flow ripple laminated sandstone (>90% sand)

Facies S3 comprises wave to combined-flow ripple laminated sandstone. The thickness varies from 0.2-10.3 m, with an average of 1.8 m (Appendix A; Figure 4). The sand is well sorted and ranges between very-fine and fine grained (0.08-0.18 mm). The basal contact is most commonly sharp or gradational and upper contacts are generally gradational. Physical sedimentary structures include wave or combined flow ripples, soft sedimentary deformation, and planar-parallel laminated to graded mudstone lamina or thin beds. Sedimentary accessories such as rootlets, carbonaceous detritus, sideritized horizons, and rare coal fragments occur sporadically. S3 overlies Facies S2, S5, M1, M2, SM1 and SM2. Facies S3 is overlain by S2, S5, M1, M2, SM1 and SM2.

Bioturbation is absent to uncommon in Facies S3 (BI 0-2) with a sporadic distribution. Traces occur as low diversity to monogeneric suites and include small-diameter deposit feeding (*Planolites, Teichichnus*), passive carnivore (*Palaeophycus*), or escape structures.

Facies S3 bears characteristics that indicate it was deposited in a marine-influenced setting subject to persistent wave agitation with subordinate unidirectional currents. The wave-ripple laminated portions are considered to represent ambient conditions, whereas the combined flow ripple lamination is interpreted to be the result of periodic fluvial flows into the basin. Planar parallel laminated and graded mudstone beds were emplaced during the waning stages of fluvial flows. The sporadic distribution of marine traces suggests the environment was physiologically stressful. The impoverished suite of diminutive forms further supports this, and indicates that the stresses could have been deposition rates, low and fluctuating salinity conditions, and unconsolidated shifting substrates. Soft sedimentary deformation is a second line of evidence for rapid deposition with abundant sediment supply. Finally, the presence of rooted tops, comminuted plant detritus, and coal fragments suggests that the depositional environment was proximal to a shoreline such that colonisation by land plant was possible. In concert, these sedimentological and ichnological characteristics support a mouth bar interpretation for Facies S3 in a marine-influenced basin.

Figure 3 Core photographs of the facies that Facies Association 2 is composed of. (A) Facies S2 from Woleebee Creek GW4, 1518.5 m. (B) Facies S4 from Woleebee Creek GW4, 1297.25 m. (C) Facies S4 from Woleebee Creek GW4, 1081.3 m. (D) Facies M2 from Roma 8, 1076.5 m. (E) Facies O2 from Taroom 17, 333.0 m. (F) Facies O1 from Chinchilla 4, 1107.40 m.



3.1.6 Facies S4: Structureless to planar-parallel laminated sandstone (>90% sand)

Facies S4 consists of structureless to planar-parallel laminated sandstone. The thickness ranges between 0.2-4.9m, and is on average 1.1 m thick (Appendix A; Figure 4). Sand grains are well sorted, varying from fine to medium-grained (0.18-0.25 mm). Basal contacts are sharp or gradational and the upper contact is generally sharp. Planar parallel lamination with interspersed structureless sections comprise the main physical sedimentary structures. Accessories include rootlets, coal fragments, sideritised horizons, and spherulitic siderite grains. The facies overlie Facies S2, M1, M2, M3, O1, and O2 and is overlain by S2, M1, M2, M3, O1, and O2.

Biogenic sedimentary structures are absent to uncommon in Facies S4 (BI 0-2). They have a sporadic distribution and consist of small-diameter *Planolites* (deposit feeding).

The overwhelming dominance of structureless to planar-parallel laminated beds and bedsets in Facies S4 is interpreted to represent periodic event-style depositional conditions with abundant sediment supply in water.

Roolets, scattered coal fragments, and spherulitic siderite suggest that the depositional environment was conducive to colonisation by land plans and probably was only periodically saturated with fresh water. The ichnogogical evidence also supports the “terrestrial” notion, as suites consist of trace forms interpreted to be due to burrowing by freshwater organisms in the soil. The stratigraphic context of Facies S4, taken in concert with the sedimentological and ichnological characteristics, point to a levee or crevasse splay depositional environment in close proximity to a meandering fluvial or distributary channel.

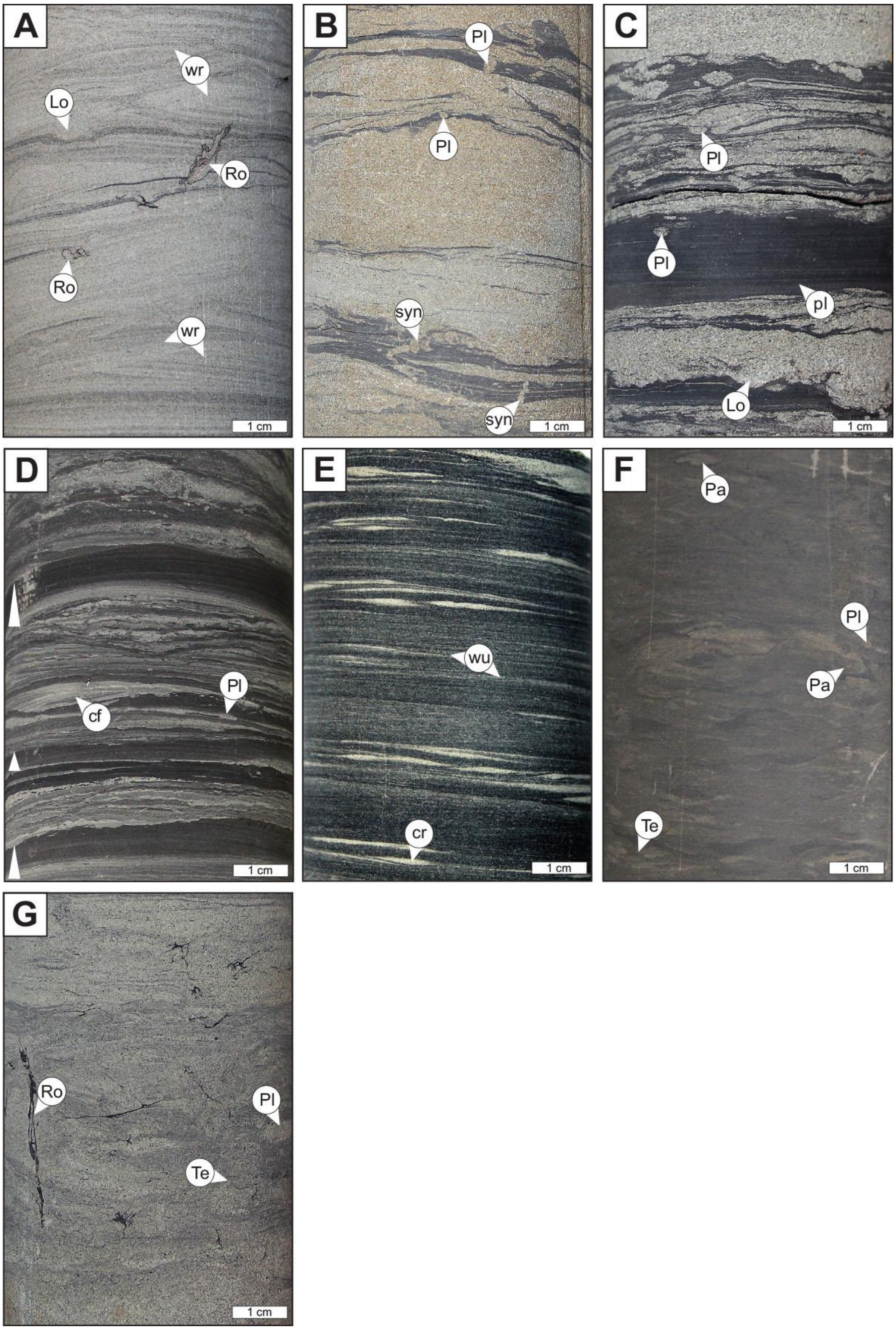
3.1.7 Facies S5: Bioturbated sandstone and muddy sandstone (>90% sand)

Facies S5 is composed of bioturbated sandstone and muddy sandstone (Appendix A; Figure 4). Facies thickness varies from 0.1-3.2 m, and is on average 0.8 m thick. Grains are moderately sorted and vary from interstitial coarse silt to fine-grained sand (0.031-0.25 mm). Bottom and top contacts are generally sharp. Physical structures are mostly not preserved due to bioturbation, but when present include planar-parallel lamination, combined flow ripples, and wave ripples. Rootlets are a very rare accessory. Facies S5 typically overlies Facies M1, M3, M4 and O3 and is commonly overlain by the same set of facies.

Bioturbation is a significant aspect of Facies S5, with bioturbation intensity that ranges from moderate to abundant (BI 3-5). Trace fossils are distributed relatively evenly throughout, and consist of a moderate diversity in faunal behaviour such as resting (*Lockeia)*, passive-carnivore (*Palaeophycus*), and deposit feeding (*Asterosoma, Chondrites, Planolites, Siphonichnus, Teichichnus, Thalassinoides*). Trace suites in beds and bedsets commonly consist of between 3-6 forms.

The sedimentological and ichnological characteristics of Facies S5 show that deposition likely occurred in marine water under low to moderate energy conditions. Rarely preserved sedimentary structures such as wave ripples and planar parallel lamination are indicative of wave agitation at the sediment-water interface, and may also be evidence of rarely preserved storm deposition. The moderate to abundant bioturbation that homogenised the sediment resulted from ambient depositional conditions that were conducive for a diverse suite of marine organisms to inhabit the substrate. Thus, the sedimentary environment must have been well oxygenated, of relatively normal marine salinities, with non-cohesive sediment substrates. Considered together with the stratigraphic context of Facies S5, the evidence supports the interpretation that it represents embayment deposits under relatively normal marine conditions.

Figure 4 Core photographs of the constituent facies of Facies Association 3. (A) Facies S3 from Taroom 17, 336.74 m. (B) Facies SM1 from Chinchilla 4, 1026.45 m. (C) Facies SM2 from Chinchilla 4, 987.70 m. (D) Facies SM3 from Roma 8, 1006.25 m. (E) Facies M1 from Taroom 17, 386.35 m. (F) Facies M3 from Taroom 17, 283.80 m. (G) Facies S5 from Chinchilla 4, 1003.75 m. (wr=wave ripples, , sn=syaeresis cracks, cf=combined flow ripples, wu=wavy undulatory lamination, cr=current ripples, Ro=rootlets, Pa=Palaeophycus, Pl=Planolites, Lo=Lockeia, Te=Teichichnus).



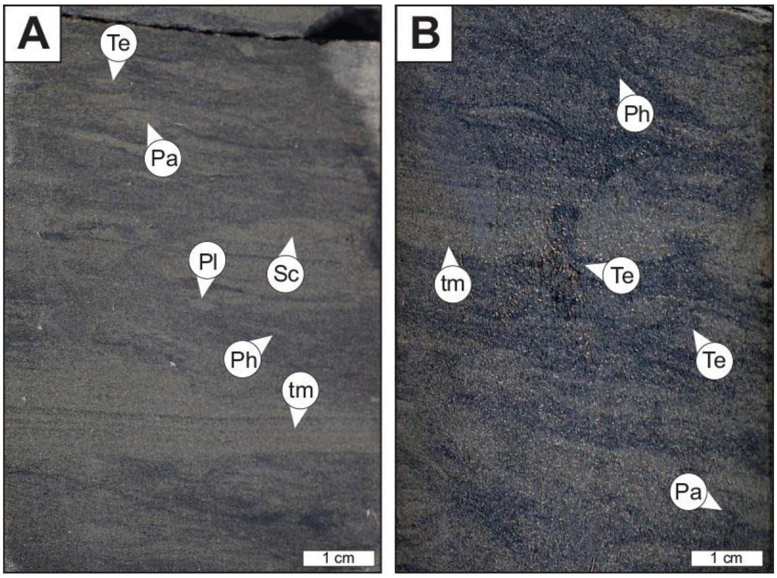
3.1.8 Facies S6: Bioturbated muddy sandstone with wave-ripple lamination and hummocky cross-stratified interbeds (>90% sand)

Facies S6 comprises interbedded bioturbated muddy sandstone and wave-ripple laminated or hummocky cross-stratified sandstone. The facies vary in thickness from 1.3-7.1 m, with an average of 3.3 m (Appendix A; Figure 5). Grain size ranges from interstitial coarse silt to medium grained sand (0.031-0.50 mm). Basal contacts are generally gradational as are the upper contacts. Physical sedimentary structures are not present in the bioturbated beds and bedsets, but in the laminated portions consist of wave ripples, micro HCS, and wavy undulatory lamination. Normal graded beds occur sporadically. No accessories are common. The facies overlie Facies S5, M1, M3, and M4, and is overlain by M4, M3, and M1.

Bioturbation has a sporadic distribution in Facies S6; in the laminated sandstone portions of the facies intensity varies from absent to sparse (BI 0-1), whereas in the muddy sandstone beds and bedsets bioturbation ranges from moderate to abundant (BI 3-5). Burrows are organised into moderate diversity suites, and traces represent a mixture of faunal behaviours such as resting (*Conichnus*, *Lockeia*), passive carnivore (*Palaeophycus*), deposit-feeding (*Asterosoma, Chondrites, Phycosiphon, Planolites, Scolicia, Teichichnus*), and sediment escape.

Facies S6 bears sedimentological and ichnological characteristics indicative of a marine setting subject to wave agitation and emplacement of event-style deposits (interpreted to represent storm deposits). The bioturbated muddy sandstone portions of the facies are considered to represent ambient/fair weather depositional conditions when energy conditions were conducive for the colonisation of substrates by marine infauna. The wave ripple laminated to micro HCS beds and bedsets are interpreted as storm-emplaced deposits. These aspects of the facies generally lack bioturbation due to high energy conditions, erosion, and rapid deposition of sediment or shifting substrates. Overall, the evidence supports the interpretation that the facies represent deposits of the upper offshore to lower shoreface in relatively normal marine salinity conditions.

Figure 5 Core photographs of Facies Association 4 and its primary facies. (A) Facies S6 from Kenya East GW7, 1013.40 m. (B) Facies M4 from Kenya East GW7, 1013.70 m. (tm=tempestite, Pa=Palaeophycus, Pl=Planolites, Te=Teichichnus, Ph=Phycosiphon, Sc=Scolicia).



3.1.9 Facies M1: Planar-parallel laminated mudstone with thin sandstone laminae (>90% mud; silt and clay)

Facies M1 consists of planar-parallel laminated mudstone with sporadically occurring thin sandstone laminae. Facies M1 varies in thickness from 0.05-6.5 m, and is on average 1.0 m thick (Appendix A; Figure 4). Grain size varies from fine to coarse silt (0.0078-0.00625 mm), and in rare instances may have a clay-sized fraction (<0.0039 mm). The siltstone laminae are very fine-grained (0.00625-0.125 mm). The facies occur above sharp lower contacts and generally pass upwards into the overlying facies across a gradational contact. Physical structures consist of horizontal planar-parallel lamination, wavy-undulatory lamination, starved current ripples and rare lenticular bedding, synaeresis cracks, normal graded beds, soft sedimentary deformation, and micro-faults. No sedimentological accessories are common. Facies M1 overlies S2, S3, S4, S5, S6, SM1, SM3, SM4, O1, O2, and O3. The facies is overlain by S2, S3, S4, S5, S6, SM1, SM3, O1, O2, and O3.

Burrowing varies from absent to uncommon (BI 0-2) in Facies M1 and has a sporadic distribution. When trace fossil are present they consist of a low diversity suite of diminutive forms representing deposit feeding (*Planolites, Teichnichnus*), passive carnivore (*Palaeophycus*), and soft-sediment swimming (navichnia) behaviours.

The nature of Facies M1 indicates deposition primarily occurred in a low energy, marine-influenced, subaqueous depositional setting. The predominance of mud-sized particles with only rarely observed sandstone laminae shows the nature of the ambient depositional conditions. Sand lamina represent periodic higher-energy events when traction transport and deposition of sand grains was possible; these likely were the result of flashy unidirectional currents derived from fluvial input. Starved ripples, normal grading, and lenticular bedsets all support this notion. The overall low diversity suite of diminutive traces that consist of facies crossing forms suggest the environment was subject to near continuous stresses on the faunal community. These likely were some combination of low and fluctuating salinity, periodic emplacement of event-beds, turbid water at the sediment-water interface, and perhaps even reduced oxygenation. When considered in the context of stratigraphic position of Facies M1, the evidence supports the interpretation that the facies represent deposition in freshwater to brackish-water interdistributary bays or their gradational equivalents on the prodelta.

3.1.10 Facies M2: Structureless mudstone (>90% mud; silt and clay)

Facies M2 is characterised by structureless mudstone. The facies range between 0.2-7.6 m thick, with an average thickness of 1.1 m (Appendix A; Figure 3). Grain size varies between fine silt and coarse silt (0.0039-0.0625 mm); the facies is well sorted. The basal contact can be either sharp or gradational, and upper contacts are typically sharp. No physical sedimentary structures are observed in the facies. The lack of visible structure may be the result of early-stage pedogenesis. Sedimentary accessories include rootlets, abundant carbonaceous detritus, and rare slickensides. Facies M2 overlies Facies S2, S4, SM4, O1, and O2. It is overlain by Facies S2, S4, SM4, O1, and O2.

Facies M2 is barren of trace fossils (BI 0).

The sedimentological characteristics of the facies suggest a very low energy depositional environment where sediment is periodically delivered by water flow from a channel, but allowed to fully dry out and begin the long process of soil formation. The lack of biogenic structures supports this interpretation, showing that the water table remained low and stable, such that it was not an appropriate niche to colonise for land-dwelling insects, crustaceans, or annelids. The abundance of organic material and roots, however, suggest that the depositional setting was appropriate for plant colonisation. Due to the nature of Facies M2, we invoke a distal lower delta plain or flood plain interpretation.

3.1.11 Facies M3: Bioturbated sandy mudstone (>90% mud; silt and clay)

Facies M3 is bioturbated sandy mudstone that ranges in thickness from 0.1-5.6 m thick and is on average 1.1 m thick (Appendix A; Figure 4). Grain size ranges between coarse silt and very fine-grained sand (0.0625-0.125 mm); the sand component occurs interstitially. Lower contacts are either gradational or sharp, and upper contacts are generally sharp. Physical structures are largely homogenised due to bioturbation, but when preserved consist of horizontal planar-parallel lamination, wavy, or lenticular bedding. No sedimentological accessories were observed. Facies M3 overlies Facies S2, S4, S5, S6, SM2, SM3, SM4, and O3, and is overlain by S2, S4, S5, S6, SM2, SM3, SM4, and O3.

Bioturbation varies from uncommon to abundant (BI 2-5) in Facies M3. Trace fossils have a relatively even distribution, and consist of low diversity assemblages representing deposit feeding (*Asterosoma, Planolites, Siphonichnus, Teichichnus, Thalassinoides*), dwellings of inferred suspension feeders (*Diplocraterion*), and domiciles of passive carnivores (*Palaeophycus*), as well as soft-sediment swimming structures (navichnia). Trace fossils are commonly diminutive in size.

Sedimentological and ichnological characteristics of Facies M3 indicate that deposition primarily occurred in a low energy, marine depositional setting subject to rare higher energy events. Abundant bioturbation by marine organisms indicates that there was ample time to homogenise the sediment between higher energy events. However, the overall small trace fossil size and low diversity assemblages point to physico-chemical environmental stress in the system. This might consist of lowered and fluctuating salinity, rapid deposition rates, reduced oxygenation, or heightened turbidity in the water column. The horizontal planar-parallel lamination shows that the environment was periodically inundated by storm events. Wavy and lenticular bedsets suggest that tidal influence was important, supporting the notion that water depths were relatively shallow. Taken together in the stratigraphic context, the evidence suggests that the most plausible interpretation for Facies M3 is a brackish-bay depositional environment.

3.1.12 Facies M4: Bioturbated sandy mudstone with wave-ripple laminated to hummocky cross stratified interbeds (>90% mud; silt and clay)

Facies M4 comprises bioturbated sandy mudstone with wave-ripple laminated to HCS interbeds. Thickness varies from 0.5-4.1 m, and is on average 2.3 m (Appendix A; Figure 5). Grain size ranges from fine silt to fine-grained sandstone (0.031-0.25 mm) through the facies. Lower contacts tend to be sharp, whereas an upward gradational transition occurs at the top. Primary physical structures include horizontal planar-parallel lamination in the mud beds and micro HCS in sand beds. Sedimentological accessories are not present. Facies M4 overlies Facies S5, and is overlain by Facies S5 and S6.

Bioturbation ranges between common and complete (BI 4-6) in the muddy beds and bedsets of Facies M4. In the laminated sand beds, bioturbation varies from absent to uncommon (BI 0-2). Traces consist of moderate-diversity assemblages of marine forms including deposit feeding (*Asterosoma, Chondrites, Planolites, Teichichnus, Phycosiphon, Helminthopsis*) and dwellings of inferred passive carnivores (*Palaeophycus*). Trace fossils occur with an even distribution in mud beds and sporadically within the laminated sands.

Facies M4 contains sedimentological and ichnological characteristics that indicate deposition in a relatively low energy marine environment, but subject to periodic emplacement of higher energy event beds. The intensely bioturbated muddy beds are the result of ambient, “fair weather” deposition when conditions were conducive for faunal colonisation of the substrate. On the other hand, laminated sandstone beds are evidence of storm deposition when energy condition sand deposition rates were higher, prohibiting colonisation of the bed until energy conditions waned. Based on these observations and considering the stratigraphic position of Facies M4, the most likely environment of deposition is the upper offshore.

3.1.13 Facies SM1: Mixed-influence sand dominated heterolithics (90%>Sand>70%)

Facies SM1 is composed of interbedded sandstone and mudstone, containing more than 70% sandstone by volume. Facies thickness spans from 0.2-45.6 m, with an average of 1.2 m (Appendix A; Figure 4). Grain size varies between medium and coarse silt (0.0156-0.0625 mm) in mud beds, and from very fine to fine-grained (0.0625-0.25 mm) in sand beds. Basal contacts are gradational and upper contacts tend to be sharp. Physical sedimentary structures include current and combined flow ripples, rare wave ripples, soft sedimentary deformation, micro-faults, synaeresis cracks, as well as normal and inverse grading in mud beds. Sedimentological accessories features such as rootlets and sideritized horizons occur sporadically. Facies SM1 overlies Facies S1, S2, S3, M1, SM2, and SM4 and is overlain by Facies S1, S2, S3, M1, SM2, and SM4.

Bioturbation in Facies SM1 ranges between absent and moderate (BI 0-3), with a sporadic distribution in muds and rare occurrence in sands. Biogenic structures consist of low diversity suites of diminutive marine traces. These are interpreted to represent behaviours such as deposit feeding (*Planolites, Siphonichnus, Teichichnus*), dwellings of inferred passive carnivores (*Palaeophycus*), resting (*Lockeia*), and sediment escape (fugichnia).

The sedimentology and ichnology of Facies SM1 gives indication of a deposition characterised by regularly alternating energy conditions and variable sediment supply in a subaqueous environment. The mixture between current, wave, and combined flow generated structures suggest a mixed-energy setting. Microfaults indicate rapid deposition of unconsolidated sediment. Synaeresis cracks suggest alternations between fresh water and brackish water conditions. This is supported by the low diversity of salinity tolerant facies crossing trace fossils. Rootlets show a close affinity to the shoreline where land-dwelling plants thrive. Taken in the context of the stratigraphy, the characteristics displayed by Facies SM1 are consistent with a proximal delta front depositional environment.

3.1.14 Facies SM2: Mixed-influence heterolithics with subequal proportions of sandstone and mudstone (70%>sand>30%)

Facies SM2 consists of interbedded sandstone and mudstone, containing between 30-70% sandstone by volume (Appendix A; Figure 4). Facies thickness ranges from 0.2-10.6 m, and is on average 1.5 m thick. Grain size varies from medium and coarse silt (0.0156-0.0625 mm) in mud beds, and from very fine to fine-grained (0.0625-0.25 mm) in sand beds. Both lower and upper contacts tend to be gradational. Primary physical structures include current and combined flow ripples, rare wave ripples, soft sedimentary deformation, micro-faults, synaeresis cracks, as well as normal and inverse grading in mud beds. Sedimentological accessories are not observed. Facies SM2 overlies Facies S1, S2, S3, SM1, SM3, and SM4 and is overlain by Facies S1, S2, S3, SM1, SM3, and SM4.

Burrowing in Facies SM2 varies from absent to moderate (BI 0-3) having a sporadic distribution in muds and very rare occurrence in sands. Bioturbation comprises low diversity assemblages of dominantly facies crossing ichnogenera that include deposit feeding (*Planolites, Teichichnus*), inferred passive carnivore dwellings (*Palaeophycus*), resting (*Lockeia*), sediment escape (fugichnia), and soft-sediment swimming (navichnia) behaviours. Trace fossils are, for the most part, diminutive.

Facies SM2 bears sedimentological and ichnological characteristics indicative of regularly alternating energy conditions and variable sediment supply in a subaqueous depositional environment. Evidence for a mixed-energy setting is manifest in the subequal proportions of current, wave, and combined flow generated physical structures. Rapid deposition rates are indicated by the presence of micro-faults, whereas synaeresis cracks show evidence of variable salinity conditions over relatively short time frames (i.e. hours to days). The low diversity suite of facies crossing marine trace fossils suggests a physiologically stressful depositional environment and these stresses might have included fluctuating salinity, reduced oxygenation, heightened water turbidity, and rapid deposition rates. Based on this and in light of the stratigraphic position of Facies

SM2, we interpret the facies to represent deposition in the distal portion of a delta front in a marine-influenced basin.

3.1.15 Facies SM3: Mixed-influence mud dominated heterolithics (30%>sand>10%)

Facies SM3 comprises interbedded sandstone and mudstone, containing between 10-30% sandstone by volume (Appendix A; Figure 4). The thickness range of the facies is from 0.1-9.0 m, with an average of 1.4 m. Grain size ranges from medium and coarse silt (0.0156-0.0625 mm) in mud beds, and from very fine to fine-grained (0.0625-0.25 mm) in sand beds. The lower contacts are sharp and upper contacts are gradational. Physical sedimentary structures include current and combined flow ripples, horizontal planar-parallel lamination, and normal and inverse grading in mud beds. Sedimentary accessories do not occur. Facies SM3 overlies Facies M1, M4, SM1, and SM2 and is overlain by Facies M1, M4, SM1, and SM2.

Biogenic reworking of Facies SM3 ranges from absent to moderate (BI 0-3) with a sporadic distribution in muds and is rarely observed in sands. Burrowing consists of a diminutive, low diversity suite of facies crossing traces that are interpreted to represent deposit feeding (*Planolites, Teichichnus*), resting (*Lockeia*), and soft-sediment swimming (navichnia) faunal behaviours.

The characteristics of Facies SM3 indicate deposition by fluctuating energy conditions with variable sediment supply in a marine-influenced depositional system. Flow conditions were predominantly quasi-steady and unidirectional, with subordinate wave influence. Horizontal planar-parallel lamination shows the importance of high flow regime conditions, and graded mud beds suggest waning flow conditions follow event-style deposition which may have been the result of high fluvial flows or the remnants of storm deposition. The low diversity suite of marine trace fossils suggests a physiologically stressful depositional environment and these stresses might have included fluctuating salinity, reduced oxygenation, heightened water turbidity, and rapid deposition rates. In stratigraphic context and with these sedimentological and ichnological characteristics Facies SM3 is interpreted to be deposits of the prodelta in a marine-influenced sedimentary basin.

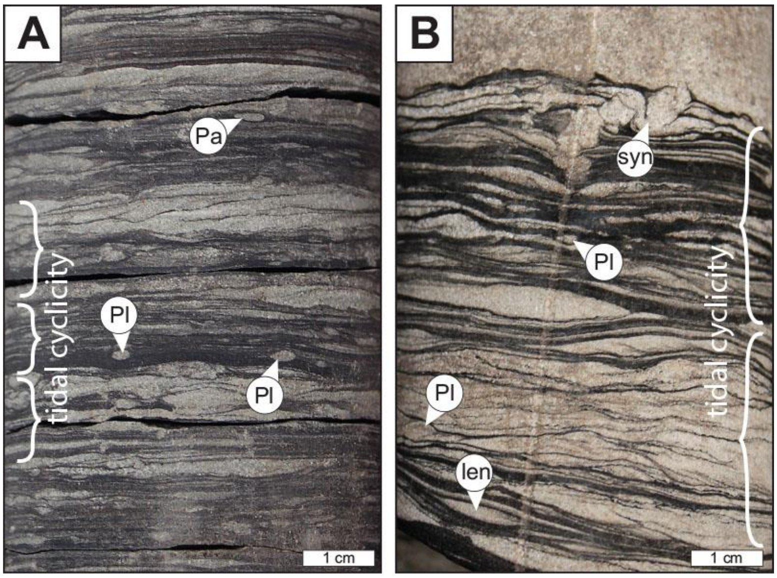
3.1.16 Facies SM4: Tide-dominated heterolithics (90%>sand>10%)

Facies SM4 is composed of tide-dominated interbedded sandstone and mudstone, containing between 10-90% sandstone by volume. Facies thickness varies between 1.1-5.4 m, and is on average 2.1 m thick (Appendix A; Figure 6). Grain size ranges from medium and coarse silt (0.0156-0.0625 mm) in mud beds, and from very fine to fine-grained (0.0625-0.25 mm) in sand beds. The lower and upper contacts are gradational or sharp. Characteristic primary structures include flaser, wavy, and lenticular bedding, current and combined flow ripples (current end-member), and synaeresis cracks. Sedimentary accessories such as carbonaceous detritus, roolets, and sideritised horizons are rare.

Bioturbation in Facies SM4 varies between absent and common (BI 0-4), having a patchy distribution both sands and muds. Burrowing comprises a low diversity suite of diminutive marine traces that are interpreted to reflect deposit feeding (*Cylindrichnus, Diplocraterion, Planolites, Siphonichnus, Teichichnus*), dwellings of inferred passive carnivores (*Palaeophycus*), and soft-sediment swimming structures (navichnia).

The facies characteristics of SM4 show that deposition occurred in a depositional environment subject to rapidly fluctuating energy conditions in a nearshore position. Shallow subaqeous to subaerial deposition is indicated by the presence of rootlets, synaeresis cracks, and physical structures indicative of high flow regime conditions with variable sediment supply (i.e. flaser, wavy, lenticular bedding). The assemblage of facies crossing, salinity tolerant, diminutive, marine traces suggests abundant physico-chemical environmental stresses that might have included low and fluctuating salinity, subaerial exposure, and heightened water turbidity. Based on the stratigraphic position of Facies SM4 and in combination with the sedimentology and ichnology, Facies SM4 is interpreted to represent tidal flat deposits.

Figure 6 Core photographs showing the facies that comprise Facies Association 4. (A) Facies SM4 (muddy end-member) from Chinchilla 4, 983.80 m. (B) Facies SM4 (sandy end-member) from Taroom 17, 302.70 m. (syn=synaeresis cracks, len=lenticular bedding, Pa=Palaeophycus, Pl=Planolites).



3.1.17 Facies O1: Coal

Facies O1 consists of banded dull to banded coal. Thickness varies 0.05-0.9 m, with an average of 0.2 m (Appendix A; Figure 3). Lower contacts are gradational or sharp and upper contacts are most commonly sharp. Facies O1 overlies Facies S4, M1, M2, and O2 and is overlain by Facies S4, M1, M2, and O2.

Bioturbation is absent from Facies O1 (BI 0).

The sedimentological characteristics of Facies O1 indicate deposition occurring in peat mires.

3.1.18 Facies O2: Carbonaceous sandstone and siltstone

Facies O2 comprises structureless carbonaceous sandstones and siltstones. Facies thicknesses range from 0.1-8.8 m, and are generally 0.7 m thick (Appendix A; Figure 3). Grain size varies from very fine silt to fine grained sand (0.0039-0.125 mm). Basal contacts are generally gradational, whereas upper contacts are sharp or gradational. Physical sedimentary structures, though rare, when present include horizontal planar-parallel lamination and current ripple lamination. Sedimentological accessories include carbonaceous detritus and coal fragments. Facies O2 overlies Facies S2, S4, M1, M2, and O1 and is overlain by Facies S2, S4, M1, M2, and O1.

Bioturbation varies between absent and sparse (BI 0-2) in Facies O2. Trace fossils observed include deposit feeding burrows of inferred terrestrial insects and annelids such as *Taenidium* and *Planolites*.

The sedimentological and ichnological characteristics of Facies O2 indicate that deposition occurred via rare subaqueous flows onto a relatively flat depositional surface subject to periodic drying out in a subaerial setting. Coal fragments and carbonaceous detritus show that plant litter was abundant and preserved due to reducing conditions in a nearby environment. The predominance of terrestrial trace fossil forms indicate that the water table was variable, but that sediment dried out on a regular basis. In the stratigraphic context of Facies O2, this suggests a proximal floodplain depositional environment.

3.1.19 Facies O3: ironstone (oolitic and cemented types)

Facies O3 is composed of ironstone. Two subtypes are noted: (1) oolitic ironstone (Facies O3A), and (2) cemented ironstone (Facies O3B. Facies thicknesses range from 0.05-1.8 m, with an average of 0.5 m

(Appendix A). Grain size in Facies O3A ranges between fine and medium-grained sand (0.125-0.5 mm); Facies O3B has overprinted original grain size and texture. The facies contain sharp basal and sharp upper contacts. Physical sedimentary structure is rare, but horizontal planar-parallel lamination occurs sporadically. Stylolites were the only sedimentary accessory present. Facies O3 overlies Facies S5, M1, and M1 and is overlain by the same set of facies.

Bioturbation is absent from Facies O3 (BI 0).

The sedimentological characteristics of Facies O3 suggest deposition in a marine sedimentary environment subject to periodic wave agitation at the sediment-water interfaces. The cemented variety of the facies probably represents diagenetic overprint of the original sedimentary fabric by hot fluids following structural features such as faults and fractures. In the context of its stratigraphic position Facies O3 is interpreted to represent a restricted marine sedimentary environment such as a trough on the shelf or a restricted embayment.

3.2 Facies associations

3.2.1 Facies Association 1 (FA1): Braid-plain (alluvial to subaerial lower delta plain)

Facies Association 1 predominantly consists of Facies conglomerates and breccias (G1, G2), braided channels (S1), with subordinate amounts of meandering channels (S2), splays (S4), floodplain muds (M2), interdistributary bays (M2), mouthbars (S3), and delta lobe (SM1, SM2) deposits (Figure 2). Typical complete facies succession comprises Facies S1 passing gradationally upwards into (and commonly interbedded with) Facies S2, and capped with M2. However, at other locations in the basin S3, SM1, and SM2 are interbedded, particularly near the top of the Precipice Sandstone succession. FA 1 reflects the early stages of Surat Basin development as braided rivers dissected the base-Surat unconformity surface following topographic lows. The rivers eroded sediment from the unconformity surface directly or transported and deposited sediment from higher topographic regions located along the basin margins. The braided system gave way to a more organised, potentially lower gradient system towards the top of the succession indicated by increasing proportions of S2, S4, and M2 upward. The presence of interbedded S3, SM1, and SM2 indicate that in places, the braid-plain flowed into a marine-influenced basin (Bianchi et al., 2018, Martin et al., 2018), perhaps even feeding a braid-delta.

3.2.2 Facies Association 2 (FA2): Lower delta plain

This facies association is composed of channels (S2), splays (S4), floodplain sands and muds (M2, O2), interdistributary bay muds (M1), and coal (O1). The primary facies succession consists of Facies S2, passing gradationally upward into S2, and capped with M2 or O2 (Figure 3). Interspersed M1 and O1 occur sporadically throughout the succession. The stratal organisation of the facies indicates a low-gradient floodplain dissected by meandering or distributary channel systems. Thin coals, rarely developed soils, presence of interdistributary bay fills, and trace fossils produced by terrestrial insects or annelids such as *Planolites* and *Taenidium* (Savrda et al., 2000) all suggest a lower lower delta plain affinity for FA2 (cf. Fielding, 1985). Thin sandstones of Facies S2 are interpreted to represent terminal distributary channels in close proximity to the subaqueous portion of the delta (Olariu and Bhattacharya, 2006). Finally, the stratigraphic stacking pattern of facies and facies associations, with marginal marine facies occurring transitionally above or below FA2 suggests that it passed laterally into nearshore and shallow marine depositional environments; this is consistent with a lower lower delta plain interpretation.

3.2.3 Facies Association 3 (FA3): Delta lobe

Facies Association 3 is dominated by mouthbar (S4), delta front (SM1, SM2, SM3), and interdistributary bay to prodelta (M1) facies (Figure 4). Subordinate muddy brackish-bay (M3) and sandy normal marine bay (S5) occur sporadically throughout the FA. Facies successions are arranged with Facies SM3 passing gradationally upward into SM2, which is in turn overlain by SM1 and then S4. This indicates progradation with a basinward shift in facies upwards. Bay deposits are interpreted to represent areas adjacent to the main delta lobe, where depositional conditions can vary from normal to reduced salinity depending upon fluvial input; Ichnological data support the variation in depositional processes and physio-chemical environmental stresses that may be the result of delta asymmetry (Bhattacharya and Giosan, 2003, Ayranci et al., 2014) or the complexities of sub-environments within a shallow water delta with numerous distributary channels (Olariu and Bhattacharya, 2006). Facies tend to be thin in FA3, commonly less than 5 m thick, and this is consistent with observations of low accommodation deltas (e.g. Fielding et al. 2006) or could be due to abundant sediment supply during sea level transgression (Lambiase et al. 2017).

3.2.4 Facies Association 4 (FA4): Tidal flats

This facies association consists of the heterolithic facies SM4, which is dominated by current- and tide-generated physical sedimentary structures (Figure 6). Bioturbation is an important element of the FA, homogenising portions of the facies and indicating that the depositional setting was occupied by marine organisms able to withstand periodic subaerial exposure, fluctuating salinity, as well as high and rapidly changing energy conditions. The presence of roots suggests this environment was nearshore. Although FA4 is not a common association in the cored intervals, it demonstrates that tides were an important sediment transport and depositional mechanisms and suggests that parts of the basin were sheltered from wave energy. The presences of tidal indicators also supports the notion of a marine-influenced basin. FA4 is interpreted to represent deposition in adjacent positions to the main delta lobes, receiving some protection from wave fetch and freshwater input into the basin.

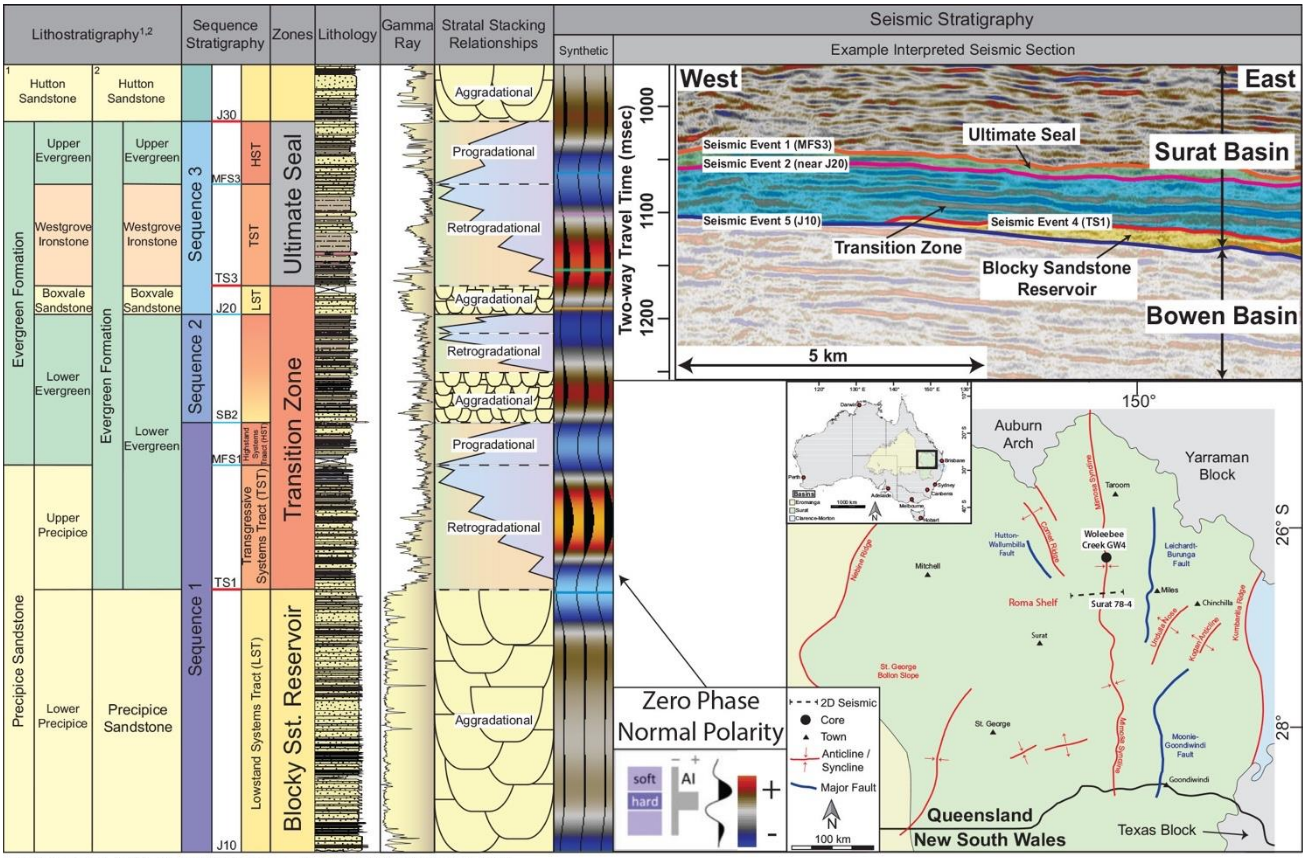
3.2.5 Facies Association 5 (FA5): Shoreface

FA5 consists of offshore mud (M4) and lower shoreface sand (S6) facies (Figure 5). The arrangement of facies in the association comprises Facies M4 passing gradationally upward into Facies S6, indicating shallowing upward in an open marine depositional setting. This reflects a change from deposition below fair-weather wave base to above fair-weather wave base where sediment was persistently agitated by wave energy. Interbedding between laminated sandstone and bioturbated mudstone indicates alternation between ambient depositional conditions and storm deposits. Abundant graded beds are produced during the waning stages of storm activity. Highly bioturbated muds with a more diverse suite of trace fossils than observed elsewhere in the Precipice Sandstone and Evergreen Formation suggests that this FA represents a marine end-member. This FA is used for comparison to interpret the restricted, low diversity assemblages that are observed in other facies and FAs.

3.3 Sequence stratigraphic terminology

The core descriptions are also used to define sequence stratigraphic surfaces and depositional cycles. The Precipice Sandstone and Evergreen Formation consist of 3 sequences from base to top. In theory each sequence will consist of a basal unconformity, a transgressive surface, a maximum flooding surface, and are marked by an unconformity at the top (which is also the base of the overlying sequence). These segment the sequences into a lowstand systems tract, transgressive systems tract, and highstand systems tract, respectively. However, only the basal and top sequences have their transgressive surface and maximum flooding surface picked; the second sequence of the three was relatively thin and these surfaces were difficult to trace across most of the basin. Thus, the stratigraphy is composed of the surfaces: J10 (base-Surat unconformity), TS1, MFS1, SB2, J20, TS3, MFS3, and J30 (top Evergreen) from base to top (Figure 7).

Figure 7 Stratigraphic terminology used to describe the core, along with the modelling zones, and a litholog from Woleebee Creek GW4.



[1]after Exon et al. 1967, Gray 1968, Rigby and Kanstler 1987, Martin et al. 2018
[2]after Mollan et al. 1972, Green et al. 1997, Wang et al. in press

3.4 Core descriptions

3.4.1 Chinchilla 4

3.4.1.1 Lowstand Systems Tract 1 (J10-TS1; 1226.6-1186.2 m)

The Precipice Sandstone rests on the J10 unconformity separating sandstone above from mudstone below (Appendix AI). The lowstand systems tract consists of a series of meter-scale fining upward braided channel sandstones (S1), with rare interspersed delta front heterolithic deposits (SM1, SM2). Overall the succession shows an aggradational facies stacking pattern, which is most distinctive in the gamma ray wireline log signature. Facies alternate between portions of a braid plain (FA1) and delta lobe (FA3). The top of the lowstand is designated by the transgressive surface at 1186.2 m.

3.4.1.2 Transgressive Systems Tract 1 (TS1-MFS1; 1186.2-1132.8 m)

Atop the transgressive surface, is a series of four stacked overall fining-upward packages. These sedimentary packages show retrogradational facies stacking and comprise distributary channel sandstone (S2) and mouthbar sandstones (S3), delta front and prodelta heterolithics (SM1, SM2, SM3), and rare interdistributary bay muds (M1). Overall the facies represent sub-environments within the lower delta plain (FA2) and delta lobe (FA3). The increasing thickness and proportion of distal facies upward through this part of the succession suggests that these deposits represent the transgressive systems tract. The top of the succession is marked by the maximum flooding surface at 1132.8 m.

3.4.1.3 Highstand Systems Tract 1 (MFS1-SB2; 1132.8-1120.8 m)

A thin highstand occurs above the maximum flooding surface at 1132.8 m. The package consists of delta front and prodelta heterolithics (SM2, SM3) that pass upward into splay sandstones (S4), interdistributary bay mudstones (M1), and coal (O1). These comprise portions of the lower delta plain (FA2) and subaqeous delta (FA3). Facies show an overall progradational stacking relationship and are therefore interpreted to represent the highstand systems tract. The succession is capped by the sequence boundary at 1120.8 m.

3.4.1.4 Sequence 2 (SB2-J20; 1120.8-1066.1 m)

Sequence 2 spans from 1120.8-1066.1 m and sits unconformably on SB2. The base of the sequence corresponding to the lowstand systems tract dominantly consists of aggradationally-stacked mouthbar sandstones (S3) and delta front heterolithics (SM1, SM2) of the delta lobe (FA3). These pass upward into interdistributary bay muds (M1), coals (O1), carbonaceous sandstones and mudstones (O2), and delta front heterolithics (SM1, SM2) that are stacked in a retrogradational manner. These represent interdigitating elements of the lower delta plain (FA2) and delta lobe (FA3). The upper portions of the succession consists of progradational prodelta heterolithics (SM3), delta front heterolithics (SM1, SM2), distributary channel sandstones (S2) of the delta lobe (FA3) and lower delta plain (FA2). The J20 unconformity erodes into the highstand deposits of Sequence 2.

3.4.1.5 Lowstand Systems Tract 3 (J20-TS3; 1066.1-1050.0 m)

Lowstand Systems Tract 3 sits atop the J20 unconformity. Within this, a series of meter-scale fining upward sandstone packages representing distributary channels (S2) are stacked with aggradational relationships. These represent the lower delta plain (FA2). The top of the lowstand is marked by a transgressive surface at 1050.0 m.

3.4.1.6 Transgressive Systems Tract 3 (TS3-MFS3; 1050.0-1006.1 m)

The transgressive systems tract spans from 1050.0-1006.1 m, resting atop a transgressive surface. The succession comprises ironstone (O3), delta front (SM1, SM2) and prodelta heterolithics (SM3), interdistributary bay (M1) and brackish bay (M3) mudstones, as well carbonaceous mudstones (O2). Together, these form a complex amalgamation of facies representing the delta lobe (FA3) and parts of the lower delta plain (FA2). Facies are stacked in an overall retrogradational pattern, and the top of the succession is a maximum flooding surface.

3.4.1.7 Highstand Systems Tract 3 (MFS3-J30; 1006.1-1483.2 m)

The highstand systems tract sits above the maximum flooding surface and consists of prodelta (SM3) and delta front heterolithics (SM1, SM2), as well as distributary channel sandstones (S2) stacked with progradational relationships. Together these form elements of the delta lobe (FA3) and lower delta plain (FA2). The highstand is incised into by the J30 unconformity, separating the Hutton Sandstone above from the Evergreen Formation below.

3.4.2 Condabri MB9-H

3.4.2.1 Lowstand Systems Tract 1 (J10-TS1; 1528.5-1483.2 m)

Lowstand Systems Tract 1 sits unconformably above J10 marking the base of Surat Basin (Appendix AI). The succession comprises stacked, aggradational, meter-scale fining-upward packages of braided channel sandstones (S1) interbedded with delta front heterolithics (SM1, SM2) and minor distributary channel sandstones (S2) representing a braid plain (FA1) interbedded with subaqueous deposits (FA3). The top of the succession is marked by the transgressive surface, separating more distal facies above from proximal facies below.

3.4.2.2 Transgressive Systems Tract 1 (TS1-MFS1; 1483.2-1450.6 m)

Above the transgressive surface at 1483.2 m sits Transgressive Systems Tract 1. The succession is composed of delta front (SM1, SM2) and prodelta (SM3) heterolithics, interdistributary bay mudstones (M1), and interspersed distributary channel sandstones (S2) representing the lower delta plain (FA2) and delta lobe (FA3). Overall facies show a retrogradational stacking pattern with progressively more distal facies occurring towards the top. The top of the transgressive systems tract is indicated by the maximum flooding surface at 1450.6 m.

3.4.2.3 Highstand Systems Tract 1 (MFS1-SB2; 1450.6-1444.2 m)

The highstand systems tract sits atop MFS1. The succession is very thin and shows only distributary channel sandstones (S2) to floodplain mudstones (M2) representing autogenic shifts within the lower delta plain (FA2). SB2 marks the top of the highstand, presumably incising and eroding portions that were previously deposited.

3.4.2.4 Sequence 2 (SB2-J20; 1444.2-1399.1 m)

The minor Sequence 2 consists of intercalated splay sandstones (S4), floodplain mudstones (M2), as well as delta front heterolithics (SM1, SM2) showing no clear aggradation, retrogradation, or progradation; thus, it is difficult to sub-divided the sequence into its constituent systems tracts. Nonetheless, the J20 unconformity occurs abruptly above the sequence at 1399.1 m.

3.4.2.5 Lowstand Systems Tract 3 (J20-TS3; 1399.1-1391.5 m)

Atop the J20 unconformity, rests a thin Lowstand Systems Tract 3. The lowstand consists of distributary channel sandstones (S2) with an aggradational stacking pattern representing the lower delta plain (FA2). Transgression is marked by the transgressive surface at the top of the lowstand.

3.4.2.6 Transgressive Systems Tract 3 (TS3-MFS3; 1391.5-1318.9 m)

Above the transgressive surface occurs Transgressive Systems Tract 3. The TST comprises six parasequences showing retrogradational stacking of distributary channel sandstones (S2), delta front and prodelta heterolithics (SM1, SM2, SM3), interdistributary bay and prodelta mudstone (M1, M4), and intervening ironstone (both oolitic and cemented types; O3). These represent slivers of lower delta plain (FA2) and much more commonly delta lobe (FA3) environments. The maximum flooding surface MFS3 denotes the top of the succession.

3.4.2.7 Highstand Systems Tract 3 (MFS3-J30; 1318.9-1300.7 m)

Finally, Highstand Systems Tract 3 is situated above MFS3 and marks the top of the Evergreen Formation. The succession is composed of progradational-stacked distributary channel sandstones (S2), delta front heterolithics (SM1, SM2), as well as interdistributary bay and prodelta mudstones (M1, M3). These show alternation between the lower delta plain (FA2) and delta lobe (FA3). The top of the highstand is eroded by the J30 unconformity, with the Hutton Sandstone subsequently stacked atop it.

3.4.3 Kenya East GW7

3.4.3.1 Lowstand Systems Tract 1 (J10-TS1; 1220.5-1187.9 m)

The base of Kenya East GW4 sits atop the base-Surat unconformity (J10; Appendix AI). The lowstand consists of a series of meter-scale fining-upward packages of braided channel sandstones (S1), with intervening intervals of conglomerates (G1). Overall, facies are stacked in an aggradational pattern and form a braid plain (FA1). The top of the lowstand is demarcated by the transgressive surface, TS1.

3.4.3.2 Transgressive Systems Tract 1 (TS1-MFS1; 1187.9-1139.2 m)

Transgressive Systems Tract 1 sits above TS1. The succession comprises six stacked parasequences that contain distributary channel sandstones (S2), delta front and prodelta heterolithics (SM1, SM2, SM3), interdistributary bay muds (M1), and rare splay sandstones (S4). Together these form parts of the lower delta plain (FA2) and delta lobe (FA3). The maximum flooding surface, MFS1, marks the top of the transgressive systems tract.

3.4.3.3 Highstand Systems Tract 1 (MFS1-SB2; 1139.2-1130.5 m)

The highstand systems tract occurs above MFS1 and is thin, extending for approximately 9 m. The succession is composed of a series of meter-scale fining-upward packages of distributary channel sandstones (S2) representing the lower delta plain (FA2). No clear progradation can be observed because the SB2 unconformity incises into the top of the highstand at 1230.5 m.

3.4.3.4 Sequence 2 (SB2-J20; 1130.5-1073.7 m)

Sequence 2 rests on SB2 and spans from 1130.5-1073.7 m. Only the basal part of the sequence was cored, probably corresponding to the lowstand systems tract. This portion consists of aggradational meter-scale fining upward packages of distributary channel sandstone (S2) representing the lower delta plain (FA2). The rest of Sequence 2 lacked core.

3.4.3.5 Lowstand Systems Tract 3 (J20-TS3; 1073.7-1061.7 m)

No core was preserved from this part of the succession.

3.4.3.6 Transgressive Systems Tract 3 (TS3-MFS3; 1061.7-993.4 m)

No core was preserved from the basal part of Transgressive Systems Tract 3. Core was present, however, from 1035-993.4 m. Here, alternating beds or prodelta mudstone and heterolithics (SM3) as well as ironstone (O3) occur representing a restricted delta lobe setting (FA3). This is capped with two coarsening-upward parasequences of offshore mudstone (M4) gradationally passing upward into lower shoreface sandstone (S6), representing a shoreface depositional setting (FA5). Finally, this is capped with alternating prodelta (SM3) and delta front heterolithics (SM1, SM2) representing the delta lobe. A maximum flooding surface caps this succession (MFS3).

3.4.3.7 Highstand Systems Tract 3 (MFS3-J30; 994.4-973.0 m)

Above MFS3, the highstand systems tract consists of prograding delta parasequences comprising distributary channel sandstones (S2), as well as prodelta (SM3) and delta front heterolithics (SM1, SM2). These represent the lower delta plain (FA2) and delta lobe (FA3). The entire succession is incised into by the J30 unconformity separating the Hutton Sandstone from the underlying Evergreen Formation.

3.4.4 Moonie 34

3.4.4.1 Lowstand Systems Tract 1 (J10-TS1; 1780.2-1758.4 m)

Lowstand Systems Tract 1 sits on the J10 unconformity. In Moonie 34, the lowstand is relatively thin, spanning from 1780.2-1758.4 m (Appendix AI). The succession consists of facies stacked in an aggradational pattern, comprising braided channel sandstones (S1) and delta front heterolithics (SM2). Together these form a braid plain (FA1), but may also indicate proximity to a braided delta. No core was available to log above the TS1 surface.

3.4.5 Reedy Creek MB3-H

3.4.5.1 Lowstand Systems Tract 1 (J10-TS1; 1351.7-1326.7 m)

Lowstand Systems Tract 1 sits on the J10 unconformity (Appendix AI). The systems tract consists of alternating packages of braided channel sandstones (S1), mouthbar sandstones (S3), and delta front heterolithics (SM2) representing the braid plain (FA1) and delta lobe (FA3) environment. The facies are generally aggradational in their stacking, not showing clear progradation or retrogradation. The top of the lowstand is capped with the transgressive surface TS1.

3.4.5.2 Transgressive Systems Tract 1 (TS1-MFS1; 1326.7-1292.1 m)

The transgressive systems tract occurs above TS1. The succession comprises beds of distributary channel sandstones (S2), mouthbar sandstones (S3), and delta front heterolithics (SM1, SM2) representing the lower delta plain (FA3) and delta lobe (FA3) environment. Facies are arranged into an overall retrogradational stacking pattern. The systems tract is marked at the top by the maximum flooding surface, MFS1.

3.4.5.3 Highstand Systems Tract 1 (MFS1-SB2; 1292.1-1268.7 m)

Above MFS1 sits Highstand Systems Tract 1. A series of progradational-stacked delta front heterolithics (SM1, SM2) and interdistributary bay mudstones (M1) compose the highstand. These represent deposition in the subaqueous portion of the delta (FA3). The highstand systems tract passes sharply into the following sequence, separated by the SB2 unconformity.

3.4.5.4 Sequence 2 (SB2-J20; 1268.7-1241.9 m)

Sequence 2 is thin in Reedy Creek MB3-H, spanning from 1268.7-1238.4 m. The sequence consists of alternating packages of prodelta and delta front heterolithics (SM1, SM2, SM3), interdistributary bay mudstones (M1), and thin, distributary channel sandstones (S2). However, most packages appear to be aggradational at the base of the sequence and retrogradational-upwards; progradational-stacked facies are rare. This probably indicates that the highstand of Sequence 2 is absent and was incised through by the J20 unconformity.

3.4.5.5 Lowstand Systems Tract 3 (J20-TS3; 1241.9-1232.1 m)

Above the J20 unconformity, occurs the very thin Lowstand Systems Tract 3. The lowstand comprises distributary channel sandstone (S2), mixed with prodelta and delta front heterolithics (SM1, SM2, SM3) in an aggradational stacking pattern. These represent the lower delta plain (FA2) and delta lobe (FA3). The top of the succession is demarcated by the transgressive surface, TS3.

3.4.5.6 Transgressive Systems Tract 3 (TS3-MFS3; 1232.1-1184.3 m)

Transgressive Systems Tract 3 spans from 1232.1-1184.3, above TS3 and below MFS3. The systems tract is rather thick, predominantly consisting of alternating facies of ironstone (O3), interdistributary bay mudstone (M1), and brackish bay mudstone (M3). Distributary channel sandstone (S2), and delta front (SM1, SM2) and prodelta heterolithics (SM3) are a subordinate constituent of the succession. Together these facies are stacked in a retrogradation fashion and form parts of a delta lobe (FA3).

3.4.5.7 Highstand Systems Tract 3 (MFS3-J30; 1184.3-1150.6 m)

Above MFS3 sits the highstand systems tract. The succession extends from 1184.3-1150.6 m. The highstand is composed of alternative distributary channel and mouthbar sandstone (S2, S3), prodelta (SM3) and delta front heterolithics (SM1, SM2), and interdistributary bay mudstone (M1). The facies are stacked in a progradational pattern, with proximal facies of the lower delta plain (FA2) generally overlying distal facies of the subaqeous delta (FA3). The highstand is capped by the J30 unconformity, marking the boundary between the Evergreen Formation and the overlying Hutton Sandstone.

3.4.6 Roma 8

3.4.6.1 Transgressive Systems Tract 1 (SB1-MFS1; 1059.7-1029.7 m)

In Roma 8 the lowstand systems tract is absent due to its paleo-elevated position on the Roma Shelf (Appendix AI). The transgressive systems tract sits unconformably on the base-Surat Unconformity (J10), atop coals, siltstones, and fine-grained sandstones of the Permo-Triassic (Bowen Basin) succession. The systems tract consists of four stacked, thinning-upward parasequences of distributary channel sandstones (S2), crevasse splay sandstones (S4), and floodplain mudstones (M2) of the lower delta plain (FA2) as well as delta front (SM1, SM2) deposits of the subaqeous delta (FA3). A retrogradational transition between facies occurs, with progressively distal facies atop proximal through the succession. The transgressive systems tract is capped with the maximum flooding surface occurring at 1029.7 m.

3.4.6.2 Highstand Systems Tract 1 (MFS1-SB2; 1029.7-1020.4 m)

The highstand systems tract is represented by a thin package of interbedded muds (M1), mouthbars (S3), and delta front heterolithics (SM1, SM2) that show an overall progradational facies stacking pattern. The facies are indicative of shifts between lower delta plain (FA2) and delta lobe (FA3) deposits, across minor flooding surfaces. In total there are 3 thin parasequences. The top of the highstand is demarcated by the succeeding sequence boundary (SB2).

3.4.6.3 Sequence 2 (SB2-J20; 1020.4-993.9 m)

Sequence 2 extends from 1020.4-993.9 m, resting unconformably atop SB2. The base of the minor sequence, corresponding the lowstand systems tract predominantly comprises mouthbars (S4), delta front heterolithics. (SM1, SM2) of the delta lobe (FA3). The transgressive and highstand systems tracts are difficult to differentiate from one another due to subtle retrogradtational and progradational facies stacking. However, they consist of four thin parasequences containing mouthbars (S3) and delta front (SM1, SM2) deposits of the delta lobe (FA3). The J20 unconformity marks the top of Sequence 2.

3.4.6.4 Lowstand Systems Tract 3 (J20-TS3; 993.9-988.2 m)

Roma 8 lacks a thick Boxvale Member sandstone atop J20. The lowstand systems tract is represented by a very thin package of interbedded mouthbars (S3) and delta front deposits (SM1, SM2, and SM3) of the delta lobe (FA3) below the ooilitic ironstone of the Westgrove Ironstone Member.

3.4.6.5 Transgressive Systems Tract 3 (TS3-MFS3; 988.2-970.0 m)

The transgressive systems tract comprises four sequences consisting of flood plain mudstone (M2) and distributary channel sandstones (S2) of the lower delta plain (FA1), delta front (SM1, SM2) and distributary channels of the delta lobe (FA3), and intervening ironstone facies (O3). These have an overall retrogradational facies stacking pattern indicating deepening upward. The top of the transgressive systems tract is demarcated by the maximum flooding surface MFS3.

3.4.6.6 Highstand Systems Tract 3 (MFS3-J30; 970.0-954.0 m)

Finally, the top of the Precipice-Evergreen succession in Roma 8 is predominantly composed of delta front (SM1, SM2) and prodelta facies (SM3) of the delta lobe (FA3). These show a progradational facies stacking pattern showing overall basinward shift in facies. These are incised into by the overlying J30 unconformity, separating the Hutton Sandstone from the top of the Evergreen Formation.

3.4.7 Taroom 17

3.4.7.1 Lowstand Systems Tract 1 (J10-TS1; 500.2-423.5 m)

The base of the Precipice Sandstone in Taroom 17 is demarcated by the J10 / base-Surat unconformity (Appendix AI). Atop this, a series of 3-6 m thick fining upward packages of braided channels (S1), with rare interspersed overbank sandstones (S4) representing a braid channel complex (FA1). The facies are stacked in an aggradational pattern, suggesting that these deposits represent the lowstand systems tract. This is capped with the transgressive surface occurring at 423.5 m.

3.4.7.2 Transgressive Systems Tract 1 (TS1-MFS1; 423.5-379.1 m)

The transgressive systems tract comprises distributary channels (S2) interbedded with mouthbars (S3) and delta front heterolithics (SM1, SM2) representing the subaqueous portion of a delta (FA3). Facies are arranged with a retrogradational stacking pattern, with each of the five parasequences getting progressively more distal upward. The transgressive systems tract is topped with the maximum flooding surface at 379.1 m.

3.4.7.3 Highstand Systems Tract 1 (MFS1-SB2; 379.1-362.3 m)

Above the maximum flooding surface, a very thin highstand systems tract occurs. It consists of two coarsening upward packages of prodelta (SM3) to delta front heterolithics (SM1, SM2) and distributary channel sands (S2) of FA3. These have a progradational pattern of facies stacking. The top of the highstand is truncated by the sequence boundary SB2.

3.4.7.4 Sequence 2 (SB2-J20; 362.3-311.1 m)

Above SB2, distributary channel sandstones (S2) pass gradationally upward into delta front (SM1, SM2) and prodelta heterolithics (SM3), as well as muds (M1). This represents aggradation of the delta lobe (FA3) consistent with the lowstand systems tract (362.3-355 m). The transgressive systems tract is represented by two fining-upward parasequences of delta lobe deposits (FA3) that show a retrogradational stacking pattern from 355-330 m. Finally, the highstand systems tract is manifest as two progradational parasequences showing the transition from the delta front (FA3) to the lower delta plain deposits of FA2. The highstand is truncated by the J20 unconformity.

3.4.7.5 Lowstand Systems Tract 3 (J20-TS3; 311.1-301.5 m)

The lowstand systems tract overlies J20 and consists of fine- to medium-grained distributary channel sandstones (S2) passing upward into delta front heterolithics (SM2). The succession is capped with transgressive surface 3 (TS3) at approximately 301.5 m.

3.4.7.6 Transgressive Systems Tract 3 (TS3-MFS3; 301.5-276.3 m)

The transgressive systems tract, overlying TS3, comprises distributary channels (S2), mouthbars (S3), and delta front heterolithics (SM1) as well as alternating bands of ironstone (O3), prodelta / interdistributary bay (M1), and brackish bay (M3) facies. Facies are organised into an overall retrogradataional stacking pattern with distal facies overlying proximal. The top of the transgressive system tract is demarcated by MFS3 at 276.3 m.

3.4.7.7 Highstand Systems Tract 3 (MFS3-J30; 276.3-270.8 m)

The highstand systems tract overlies MFS3 and is composed of prodelta mudstones (S1) and rare distal delta front heterolithics (SM2). The unit is thin, but shows an inconspicuous progradational stacking pattern that is top-truncated indicating erosion associated with the overlying sequence boundary. The top of the highstand is marked by the base of the Hutton Sandstone (J30).

3.4.8 West Wandoan 1

3.4.8.1 Lowstand Systems Tract 1 (J10-TS1; 1237.0-1163.0 m)

The lowstand systems tract at the base of West Wandoan 1 sits above the sub-Surat unconformity (J10; Appendix AI). It predominantly comprises a series of stacked braided channel deposits (S1) with interspersed lag deposits (G1) and rare distributary channel sandstones at the top (S2). These show an aggradational facies stacking pattern, with no clear progradation or retrogradation apparent. The lowstand systems tract is capped by a transgressive surface occurring at 1163.0 m.

3.4.8.2 Transgressive Systems Tract 1 (TS1-MFS1; 1163.0-1112.5 m)

Above the transgressive surface, the transgressive systems tract is characterised by alternating delta front (SM1,SM2), and prodelta (SM3) facies, with minor carbonaceous (O2) bedsets. The majority of the transgressive system tract was inferred from wireline logs as core is missing between 1146 m and 1061 m.

3.4.8.3 Highstand Systems Tract 1 (MFS1-SB2; 1112.5-1093.5 m)

The highstand systems tract was interpreted using wireline logs to span from 1112.5-1093.5 m.

3.4.8.4 Sequence 2 (SB2-J20; 1093.5-1036.0 m)

The base of sequence 2 was inferred from wireline logs to occur at 1093.5 m. This corresponds to the lowstand and transgressive systems tract. The highstand systems tract was captured in core, and extends from 1061 m to 1036 m. This consists of alternating distributary channel sandstones (S2), mouthbar sandstones (S3), delta front heterolithics (SM1, SM2), and prodelta (SM3) heterolithics. Facies are organised into a progradtaionl stacking pattern with progressively more proximal facies overlying distal facies upwards. The top of the sequence is marked by the J20 unconformity at 1033.1 m.

3.4.8.5 Lowstand Systems Tract 3 (J20-TS3; 1036.0-1033.1 m)

Above J20, a thin lowstand systems tract occurs consisting of distributary channel (S2), and interdistributary bay to prodelta (M1, SM3) facies. Facies are arranged in an aggradational stacking pattern. The top of the lowstand is capped by a transgressive systems tract at 1033.1 m.

3.4.8.6 Transgressive Systems Tract 3 (TS3-MFS3; 1033.1-965.1 m)

Atop the transgressive surface, the transgressive systems tract consists of a series of retrogradationally stacked distributary channel sandstones (S2), delta front heterolithics (SM2), prodelta muds and heterolithics (M1, SM3), and ironstone bands (O3). Three distinct fining upward cycles are noted: from 1033.1 m to 1008.5 m, from 1008.5 m to 980.5 m, and from 980.5 m to 965.1 m. The top of the transgressive systems tract is marked by a maximum flooding surface.

3.4.8.7 Highstand Systems Tract 3 (MFS3-J30; 965.1-953.8 m)

The highstand systems tract is very thin, spanning from 965.1 m to 953.8 m. The succession consists of progradationally-stacked prodelta heterolithics (SM3), delta front heterolithics (SM1, SM2), and thin terminal distributary channel sandstones (S2; cf. Olariu and Bhattacharya, 2006). The top of sequence 3 / the highstand systems tract is marked by an erosive contact (J30) above which planar tabular cross bedded sandstones containing mud-clast rip ups are seated. This is the transition into the overlying Hutton Sandstone.

3.4.9 Woleebee Creek GW4

3.4.9.1 Lowstand Systems Tract 1 (J10-TS1; 1573.6-1468.6 m)

The base-Surat unconformity (J10) in Woleebee Creek GW4 is manifest as a sharp, erosive contact with coarse-grained structureless or planar-tabular cross bedded sandstone containing rip up clasts (S1), and thin bands of sandstone supported conglomerate (G2; Appendix AI). The entire lowstand systems tract consists of a series of amalgamated, small-scale (i.e. 2-6 m thick) fining-upward packages representing a braid plain (FA1). Rare, thin planar-laminated or structureless mudstone beds and bedsets are scattered throughout (M1 or M2) and these represent the flood plain of a lower gradient delta system (FA2). The lowstand succession is capped with TS1 occurring at 1468.7 m.

3.4.9.2 Transgressive Systems Tract 1 (TS1-MFS1; 1468.6-1418.9 m)

The transgressive systems tract is characterised by an overall muddier-upward succession. A series of fining-upward packages of distributary channel sandstones (Facies S2), and coarsening upward packages of heterolithic delta front deposits (Facies SM1, SM2) that become increasingly marine-influenced up section are the main units and are interpreted as parasequences. Parasequences vary between 3-7 m thick. There are five parasequences in in total representing the lower delta plain (FA2) passing upward into delta lobe (FA3) deposits with an overall retrogradational stacking pattern. A maximum flooding surface occurs at the top of the transgressive systems tract at 1418.9 m.

3.4.9.3 Highstand Systems Tract 1 (MFS1-SB2; 1418.9-1399.5 m)

Three overall coarsening upward packages (parasequences) characterise the highstand systems tract. They consist of delta front (FA2) deposits passing upward into lower delta plain sediments (FA2), indicating progradational facies stacking pattern. The highstand systems tract thin with the SB2 surface occurring at 1400 m.

3.4.9.4 Sequence 2 (SB2-J20; 1399.5-1356.3 m)

Sequence 2 overlies SB2, a sharp interface between sandstones and mudstones of the highstand of Sequence 1 and mud-clast breccia and fine-grained sandstone of the lowstand of Sequence 2. The facies are interpreted to represent distributary channels (Facies S2), mouth bars (Facies S4), and delta front deposits (SM1, SM2) of FA3 with an aggradational stacking pattern (1399.2-1391 m). These pass upward into mouthbars (Facies S4), bay mudstones (Facies M2), and delta front deposits (SM1, SM2) of FA3 with a retrogradational stacking pattern (1391-1356.2 m). It appears that the highstand systems tract is truncated due to erosion from the J20 sequence boundary.

3.4.9.5 Lowstand Systems Tract 3 (J20-TS3; 1356.3-1344.5 m)

The lowstand systems tract from Sequence 3, otherwise known as the Boxvale Sandstone Member, is marked by an abrupt lithological change from the underlying mudstone across the J20 unconformity. The lowstand extends from 1356.3-1344.5 m, and consists of fine-grained distributary channel sandstones (Facies S2) of the lower delta plain (FA2). The transgressive surface tops the lowstand deposits.

3.4.9.6 Transgressive Systems Tract 3 (TS3-MFS3; 1344.5-1305.4 m)

A rapid deepening of sedimentary facies occurs above the transgressive surface, where facies shift from fine-grain sands below to alternating thin packages of delta front (SM1, SM2, SM3), bay muds (M2), and oilitic ironstone (O3) and these generally are interpreted to represent a restricted marine environment or subaqueous portion of a delta (FA3). Eight individual layers of ironstone occur in this portion of the succession, and these are interpreted to reflect 8 separate parasequences. The top of the transgressive systems tract is demarcated by the maximum flooding surface (1305.4 m).

3.4.9.7 Highstand Systems Tract 3 (MFS3-J30; 1305.4-1285.2 m)

Finally, the top of the Evergreen Formation in Woleebee Creek GW4 comprises the highstand systems tract (1305.4-1285.2 m). This consists of a series of coarsening- and thickening-upward cycles showing progradational facies stacking patterns of delta front (SM2, SM3), mouthbar (S4), and distributary channel (S2) deposits. The top of the succession is incised into by the overlying Hutton Sandstone, across the J30 unconformity. This is marked by thick planar-tabular cross stratified sandstones (S2), containing intervals of mud-clast breccia (G2).

4. Discussion

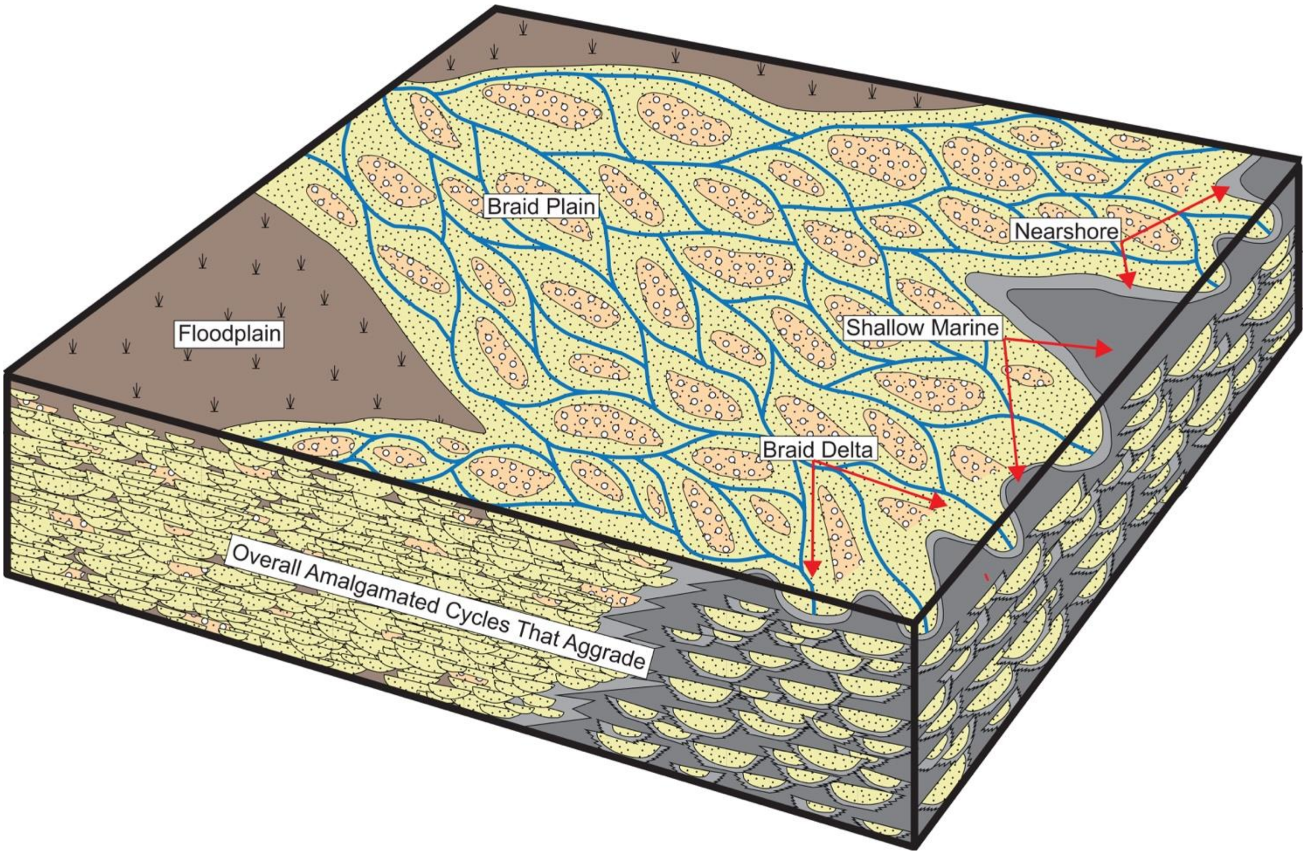
4.1 Conceptual depositional models

Conceptual block models were constructed for the main components of the Precipice-Evergreen succession. These models show the major depositional environments, and their stratal stacking relationships to help better envision the distribution of facies and flow units within the basin. However, they do not hold any significance with respect to the orientation of depositional systems or the relative proportion of environments, a topic that is addressed in the technical report dealing with neural network facies predictions and paleogeogeographic distribution of facies.

4.1.1 Lowstand Systems Tract 1 (J10-TS1)

Figure 8 shows the conceptual depositional model for the Precipice Sandstone between J10 and TS1, representing the lowstand systems tract. The model indicates that the bulk of accommodation space was filled with sediments representing braid plains (FA1), with subordinate shallow marine environments such as the delta lobe (FA3). These were stacked in an aggradational pattern, neither prograding nor retrograding.

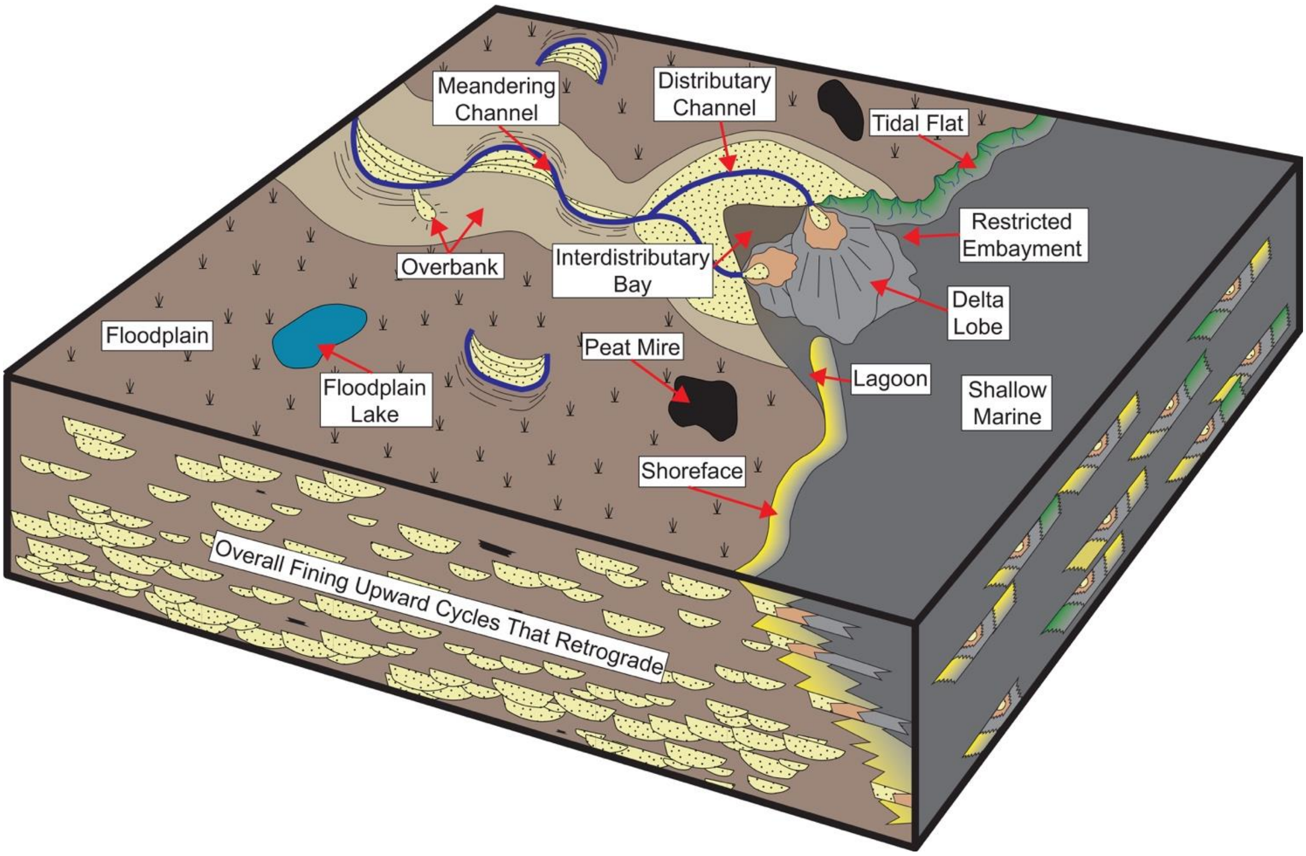
Figure 8 Conceptual block model of Lowstand Systems Tract 1, the main reservoir interval being investigated for CO_2 storage in the Surat Basin.



4.1.2 Transgressive Systems Tract 1 (TS1-MFS1)

A conceptual depositional model for Transgressive Systems Tract 1 is indicated in Figure 9, the part of the succession lying between TS1 and MFS. The model indicates that deposition occurred within a complex palaeogeography consisting of a large-scale deltaic system, which itself comprises a lower delta plain (FA2), delta lobe (FA3), and with subordinate elements of tidal flat (FA4) and shoreface (FA5) systems. Strata show overall backstepping relationships with deepening of sedimentary environments with time. A similar depositional model is suggested for the minor transgressive systems tract contained within Sequence 2.

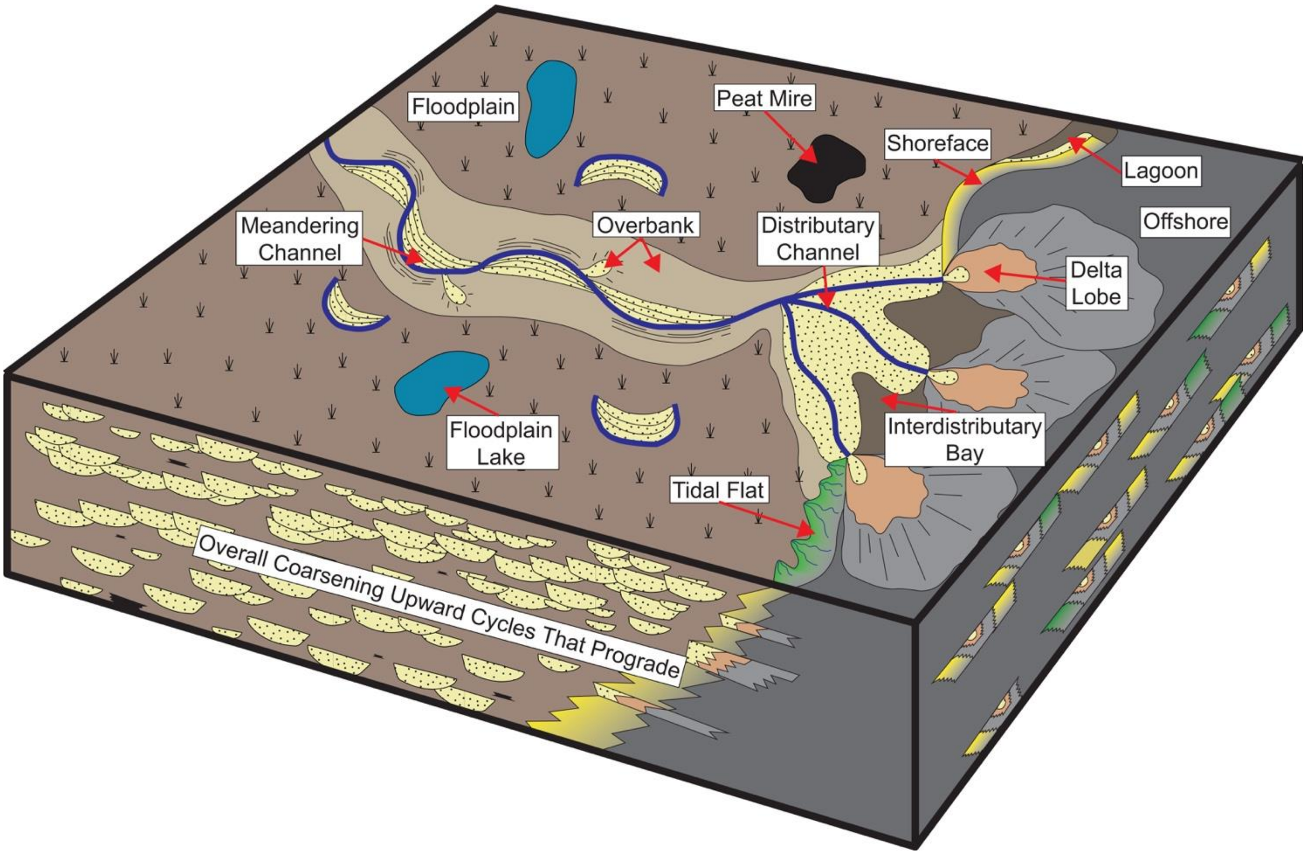
Figure 9 Conceptual block model for Transgressive Systems Tract 1, the unit overlying the main reservoir interval. The same depositional model is applicable to the transgressive systems tract within Sequence 2.



4.1.3 Highstand Systems Tract 1 (MFS1-SB2)

The depositional model for Highstand Systems Tract 1, between MFS1 and SB2, is displayed in Figure 10. Deposition of the highstand was within the same palaeogeography that the transgressive systems tract was deposited, though depositional environments were progradational overall. Thus, cross-cutting and complex facies relationships were common – possibly the result of low depositional gradients where small changes in relative base level resulted in large shifts in environments of deposition. Nonetheless, the highstand consisted of lower delta plain (FA2), delta lobe (FA3), and with subordinate elements of tidal flat (FA4) and shoreface (FA5) systems. Within Sequence 2, the thin highstand probably had a similar arrangement of facies and environments; so too did Highstand Systems Tract 3, although it probably had increasing marine influence on deposition.

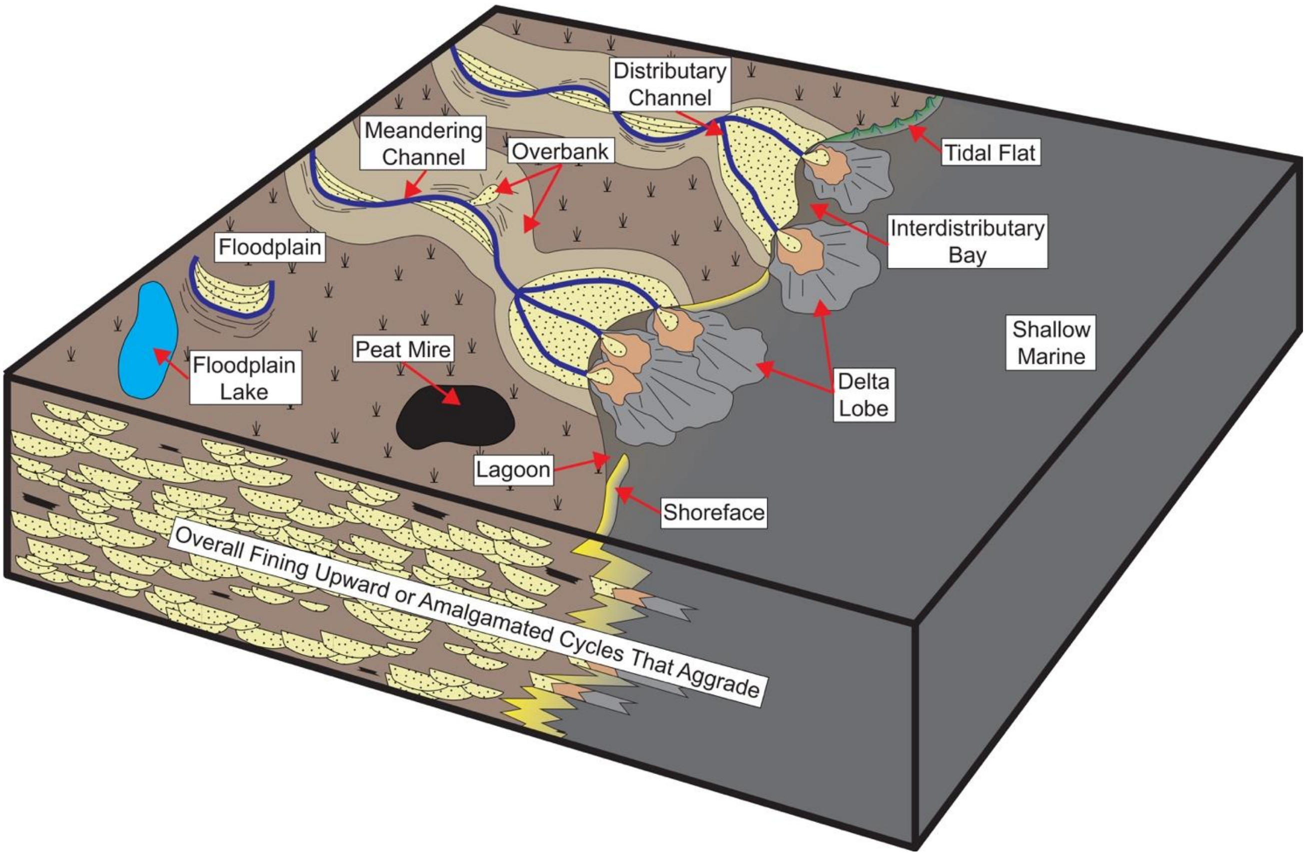
Figure 10 Conceptual block model for Highstand Systems Tract 1. The same model is applicable to the highstand systems tract from Sequence 2, as well as Highstand Systems Tract 3.



4.1.4 Lowstand Systems Tract 3 (J20-TS3)

The model for Lowstand Systems Tract is shown in Figure 11. The same large-scale fluvio-deltaic system that was occupying the Surat Basin was present up until this time (broadly equivalent to the Boxvale Sandstone Member). Complex facies relationships prevailed, but overall depositional environments comprised lower delta plain (FA2), delta lobe (FA3), and with subordinate elements of tidal flat (FA4) and shoreface (FA5) systems. These did not show progradation or retrogradation at the sequence scale, thus, are inferred to be stacked in an aggradational fashion. The lowstand systems tract from Sequence 2 probably looked similar.

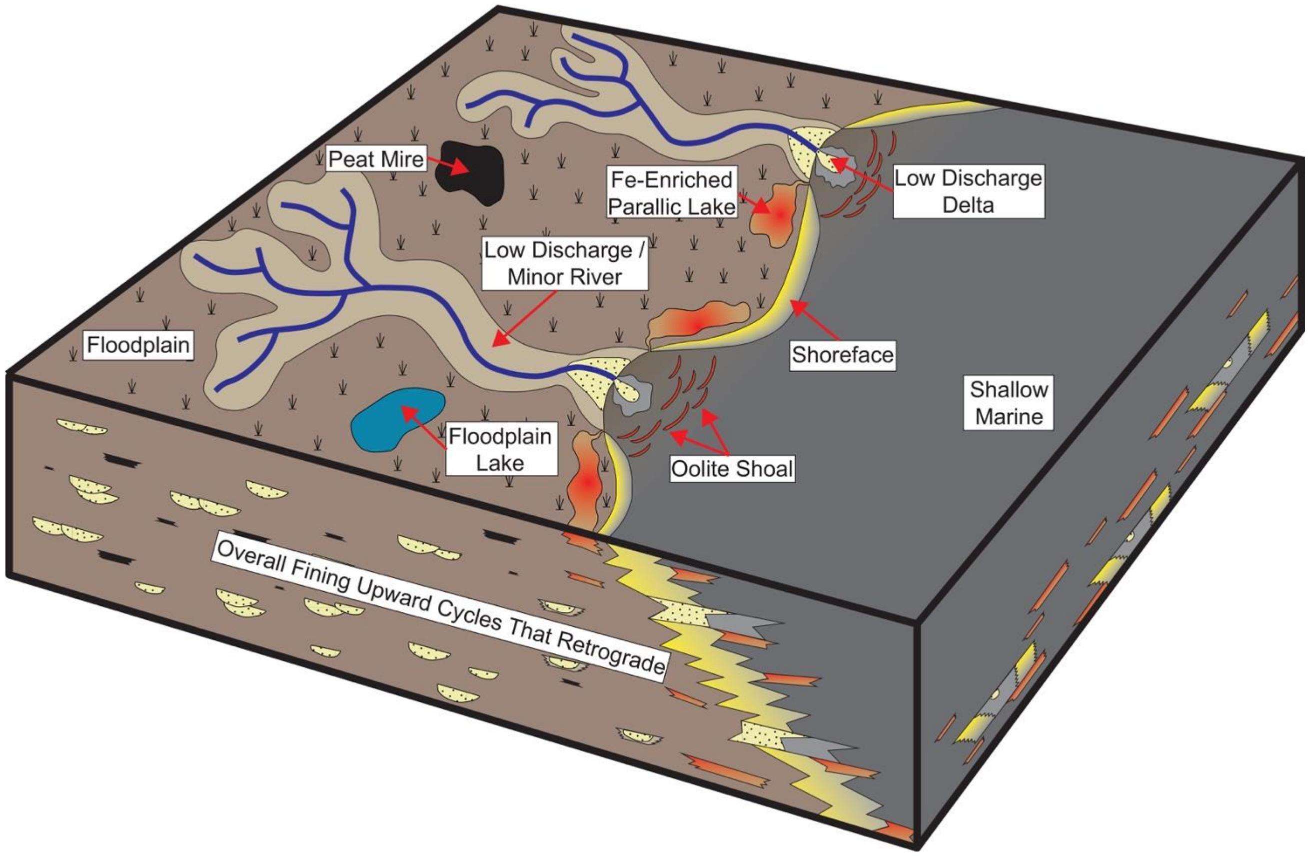
Figure 11 *Conceptual block model for Lowstand System Tract 3, otherwise known as the Boxvale Sandstone. A similar model applies to the lowstand from Sequence 2.*



4.1.5 Transgressive Systems Tract 3 (TS3-MFS3)

The conceptual model for Transgressive System Tract 2, the interval containing ironstone horizons, is depicted in Figure 12. The overall depositional setting is envisioned as a low gradient system, with minor rivers and streams flowing into a marine basin. During deposition of Transgressive Systems Tract 3, the lower delta plain and shallow marine realm were still of low gradient, such that small changes in base level would have resulted in large shifts of facies belts. Portions of the lower delta plain (FA2), delta lobe (FA3), and minor tidal flat (FA4) and shoreface (FA5) elements would have been present and overall deposition would have been under deepening conditions with time as environments were transgressed by rising relative sea level. The dominant environment consisted of a restricted delta front or estuary where iron-enrichment was able to take place under slight wave agitation resulting in deposition of the oolitic ironstone bands. Minor paralic lakes and bays probably also would have accumulated ironstone, being in connection to the basin and sharing similar chemistry.

Figure 12 Conceptual block model for Transgressive Systems Tract 3, the main interval containing ironstone.



5. Conclusions and recommendations

In conclusion, the Precipice Sandstone and Evergreen Formation in the Surat Basin consist of 19 distinctive depositional facies that can be organised into five main depositional environments:

1) braid plain,
2) lower delta plain,
3) delta lobe,
4) tidal flats, and
5) shoreface.

The Precipice Sandstone dominantly consisted of aggradational-stacked facies within a broad braided river to braid delta complex forming the main reservoir interval for the UQ-SDAAP project.

These pass upwards into a series of prograding and retrograding fluvio-deltaic environments which form the “Transition Zone” wherein pressure build up and CO_2 migration ultimately dissipates.

Near the top of the Evergreen Formation, peculiar depositional conditions prevailed such that iron-rich sediments were deposited on the distal coastal plain and shallow marine realm forming oolitic ironstone. This forms the “Ultimate Seal” complex for the interval of interest.

In terms of investigating the specific notional injection sites, we propose that core must be collected in order to characterise the sedimentary facies and environments and to determine the thickness and quality of the Transition Zone and Ultimate Seal complex. Thus, an idealised core interval would commence at the J30 unconformity (the base of the Hutton Sandstone) and intersect the J10 unconformity at the base of the Surat Basin.

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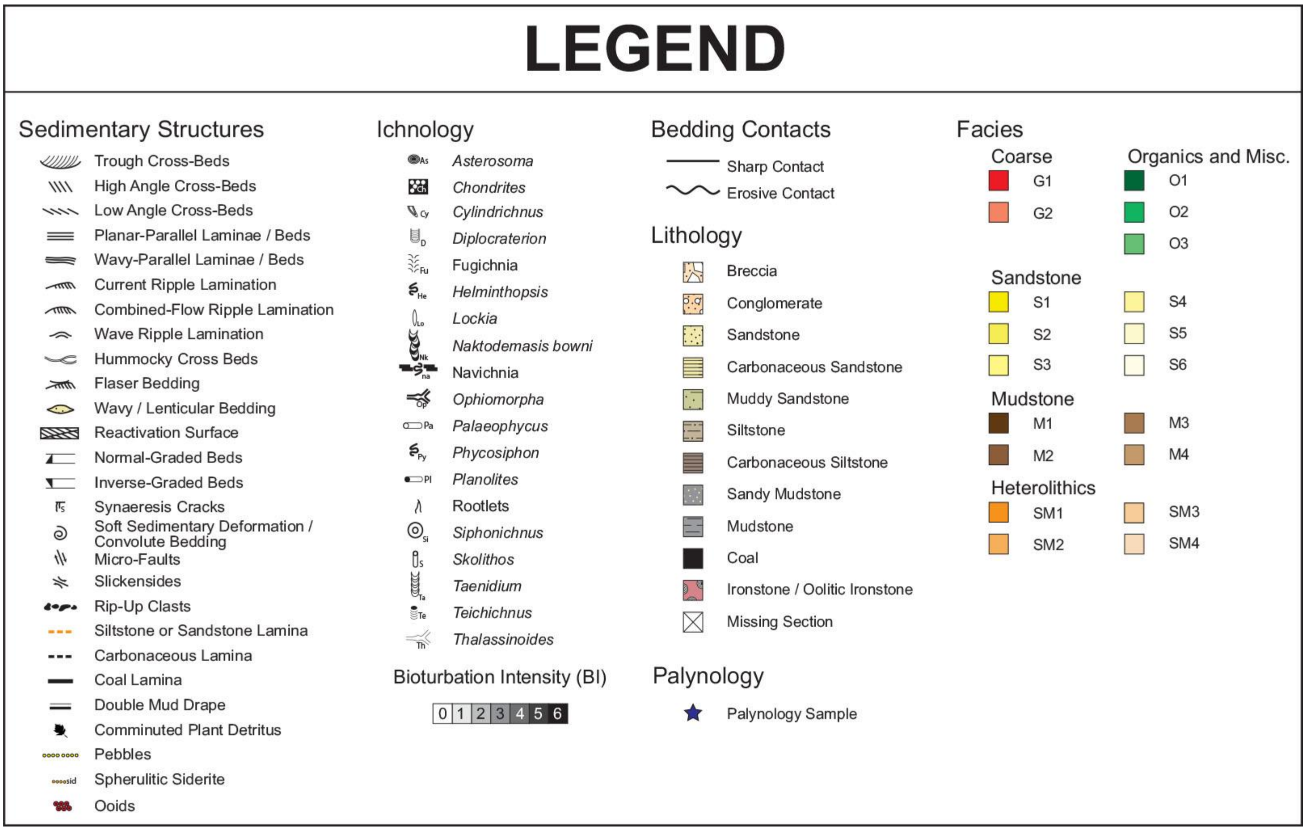
7. Appendices

7.1 Appendix A



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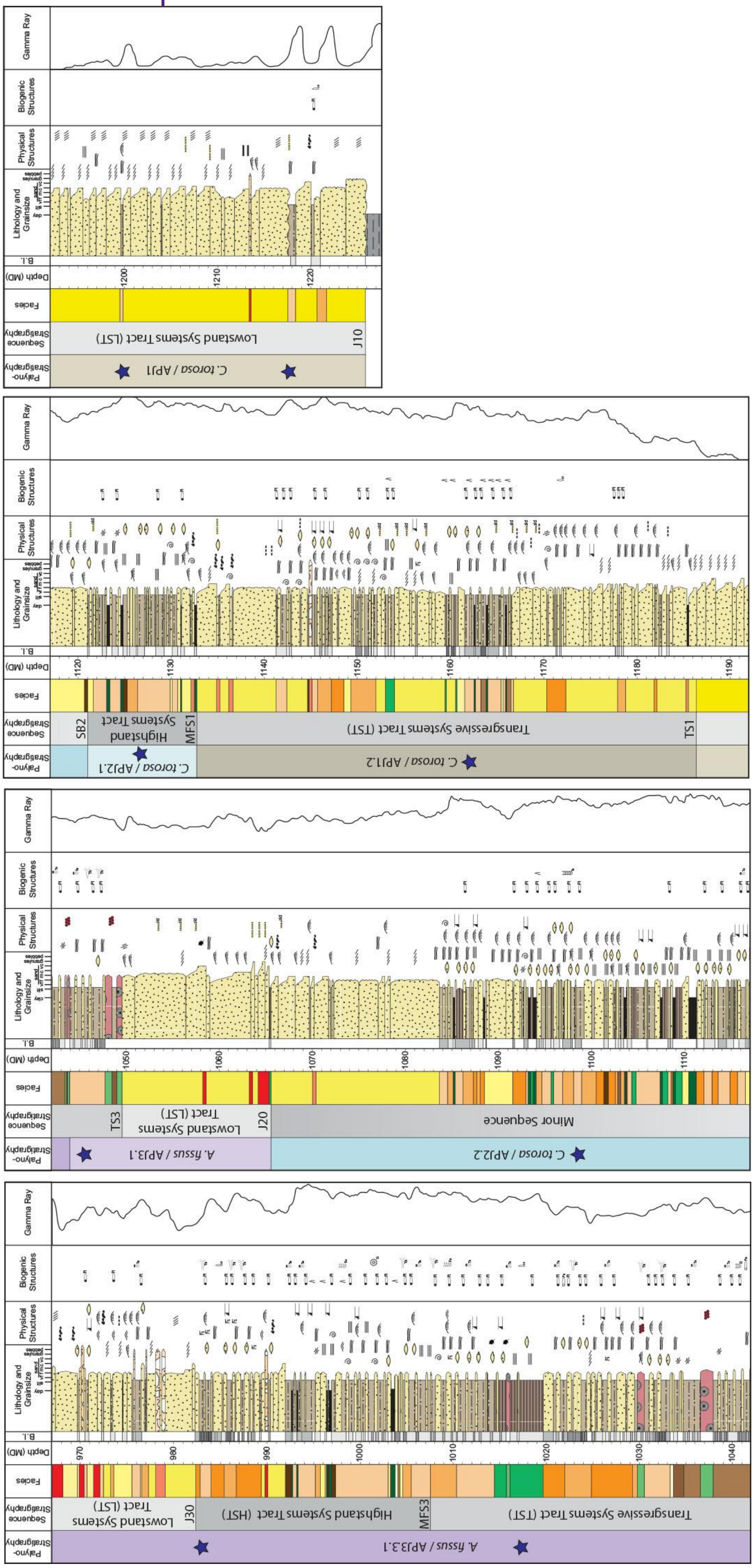

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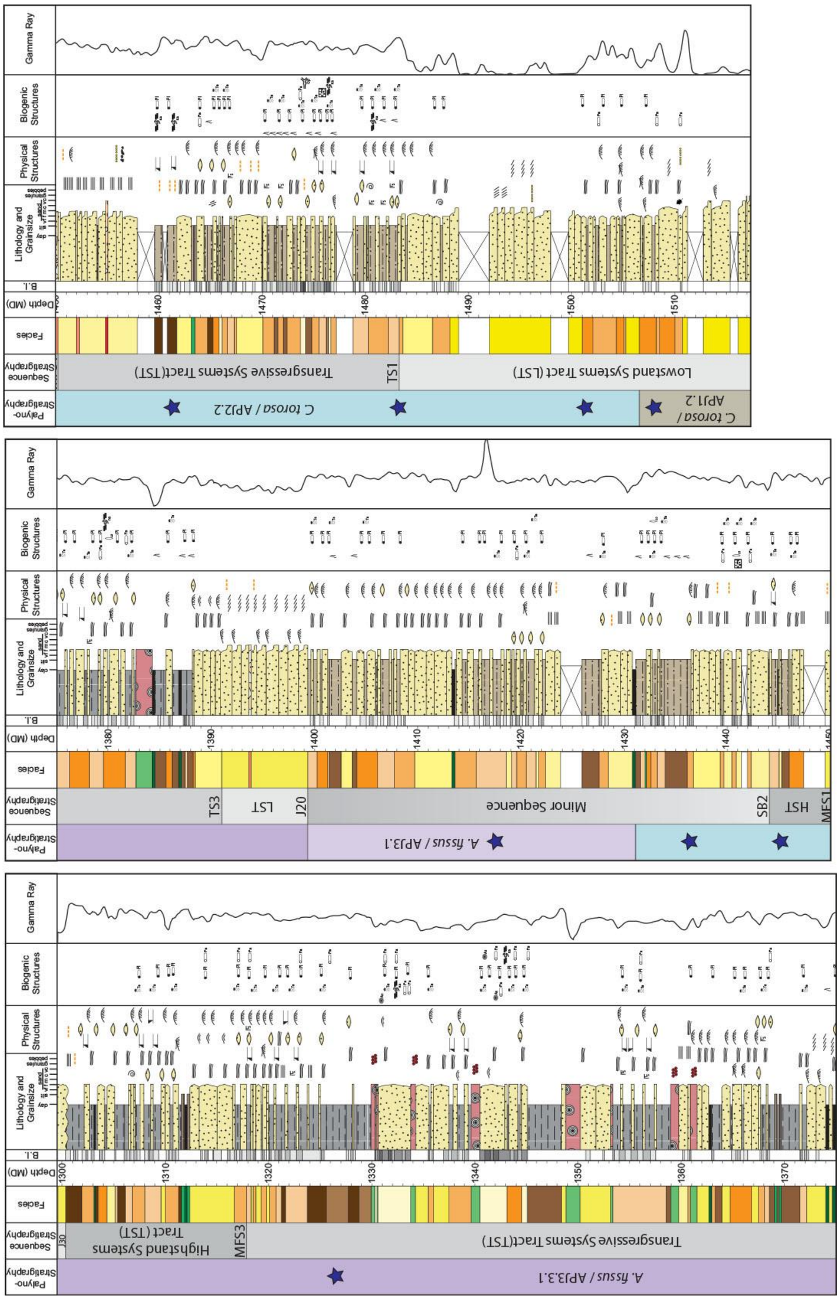

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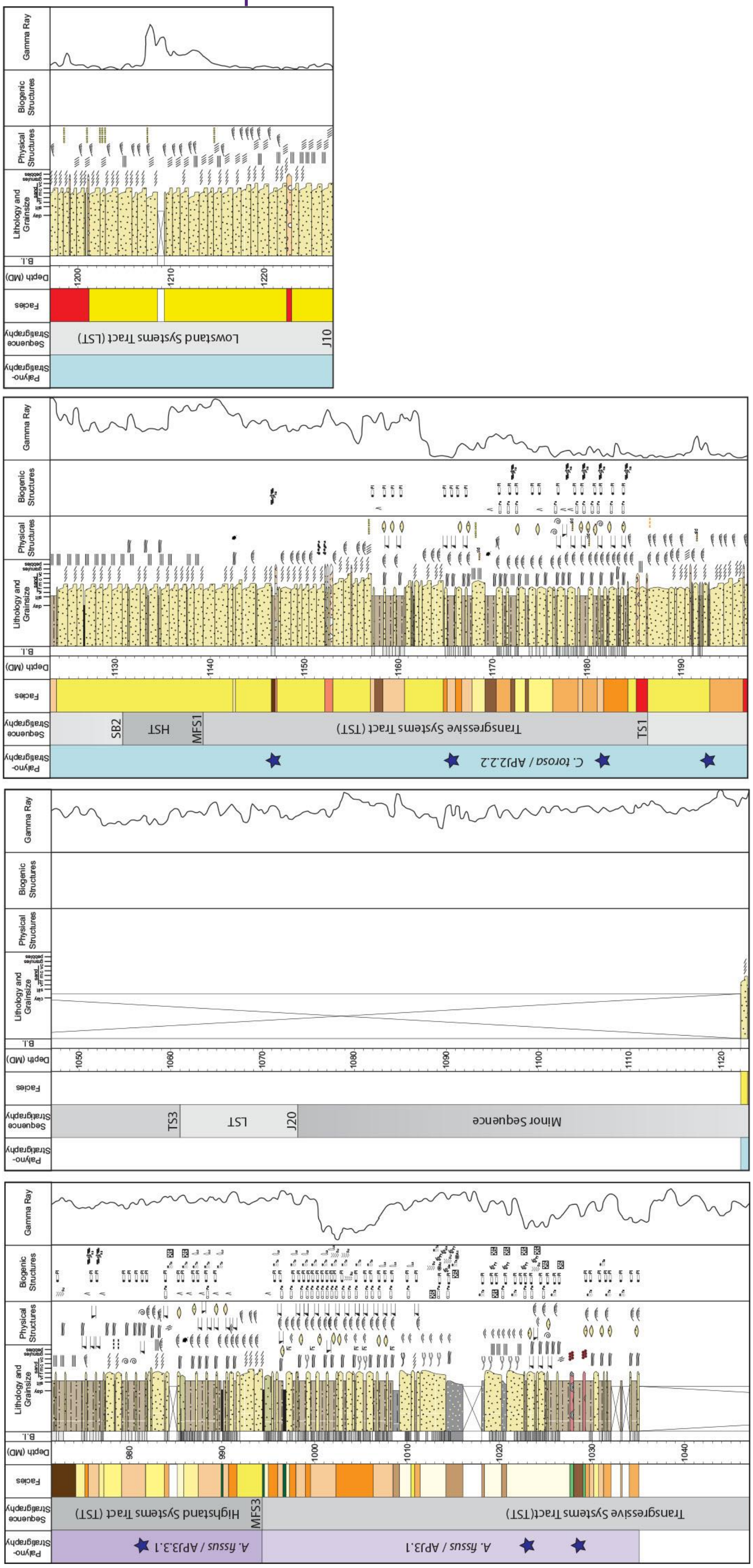

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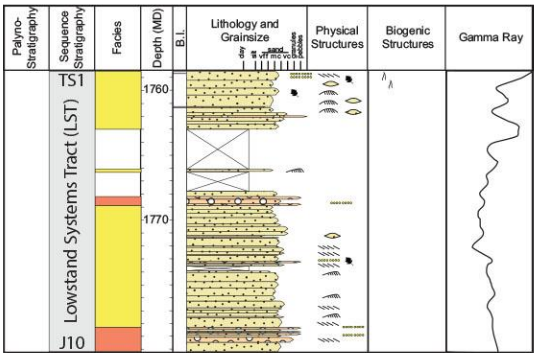

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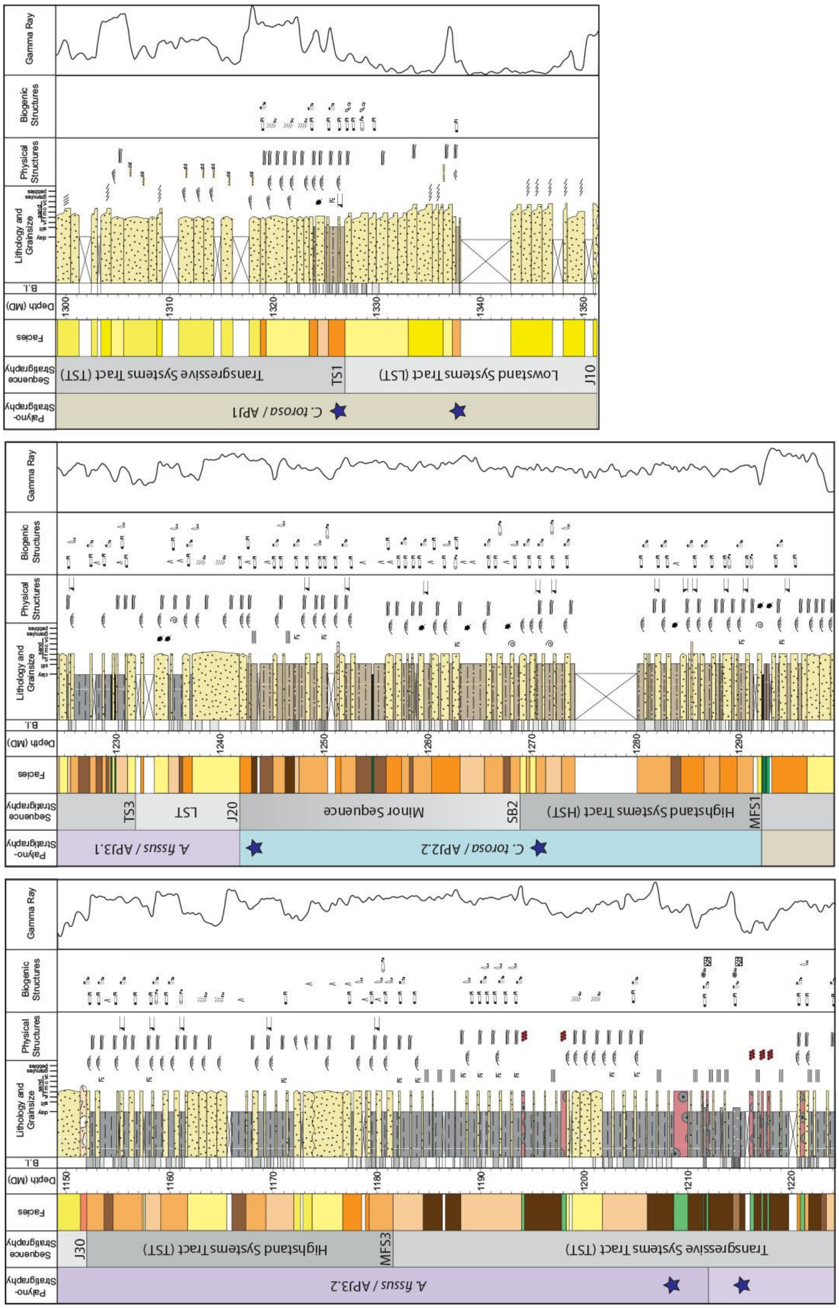

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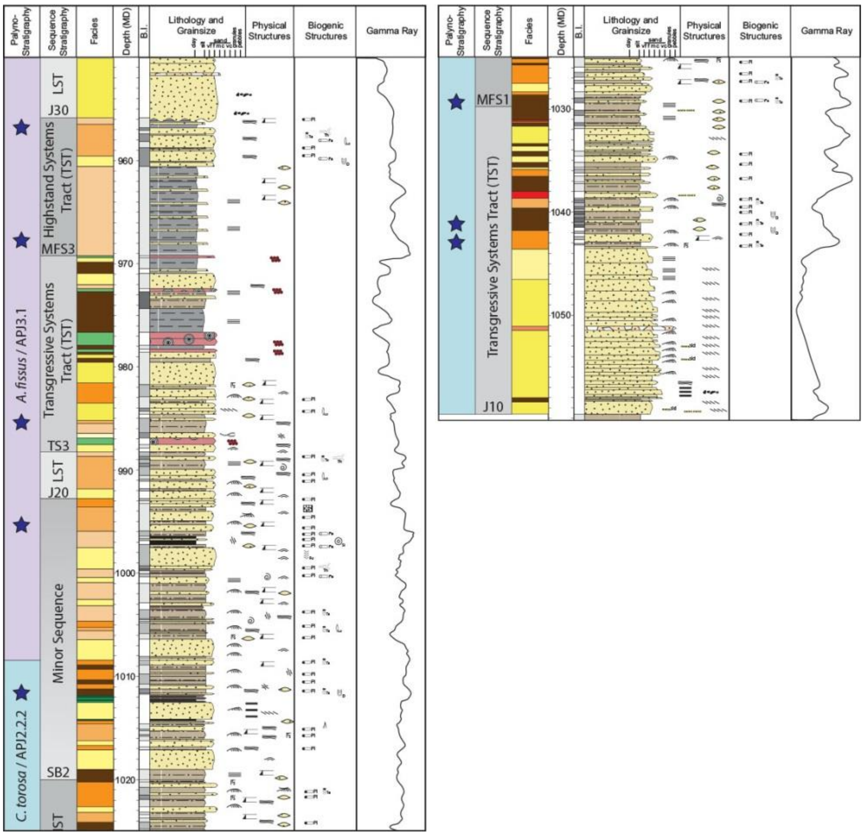

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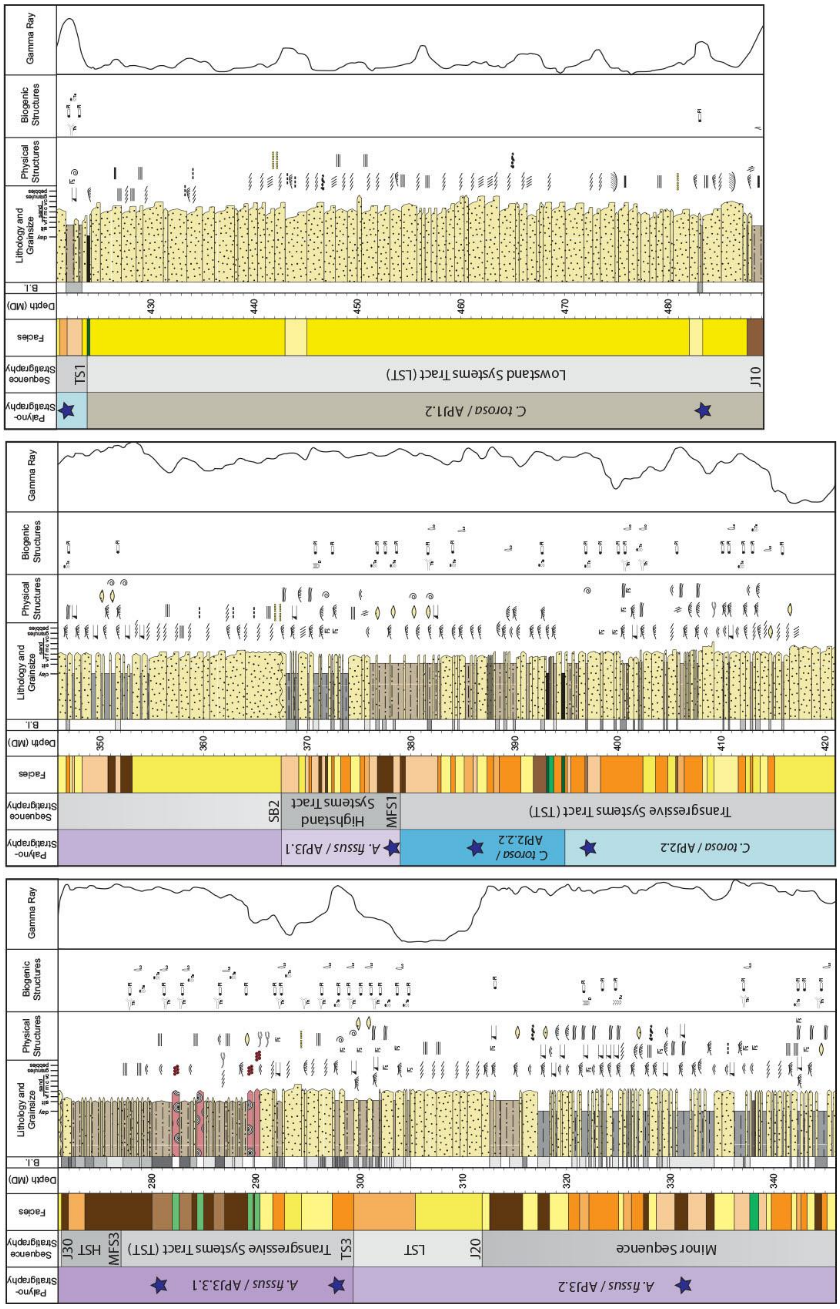

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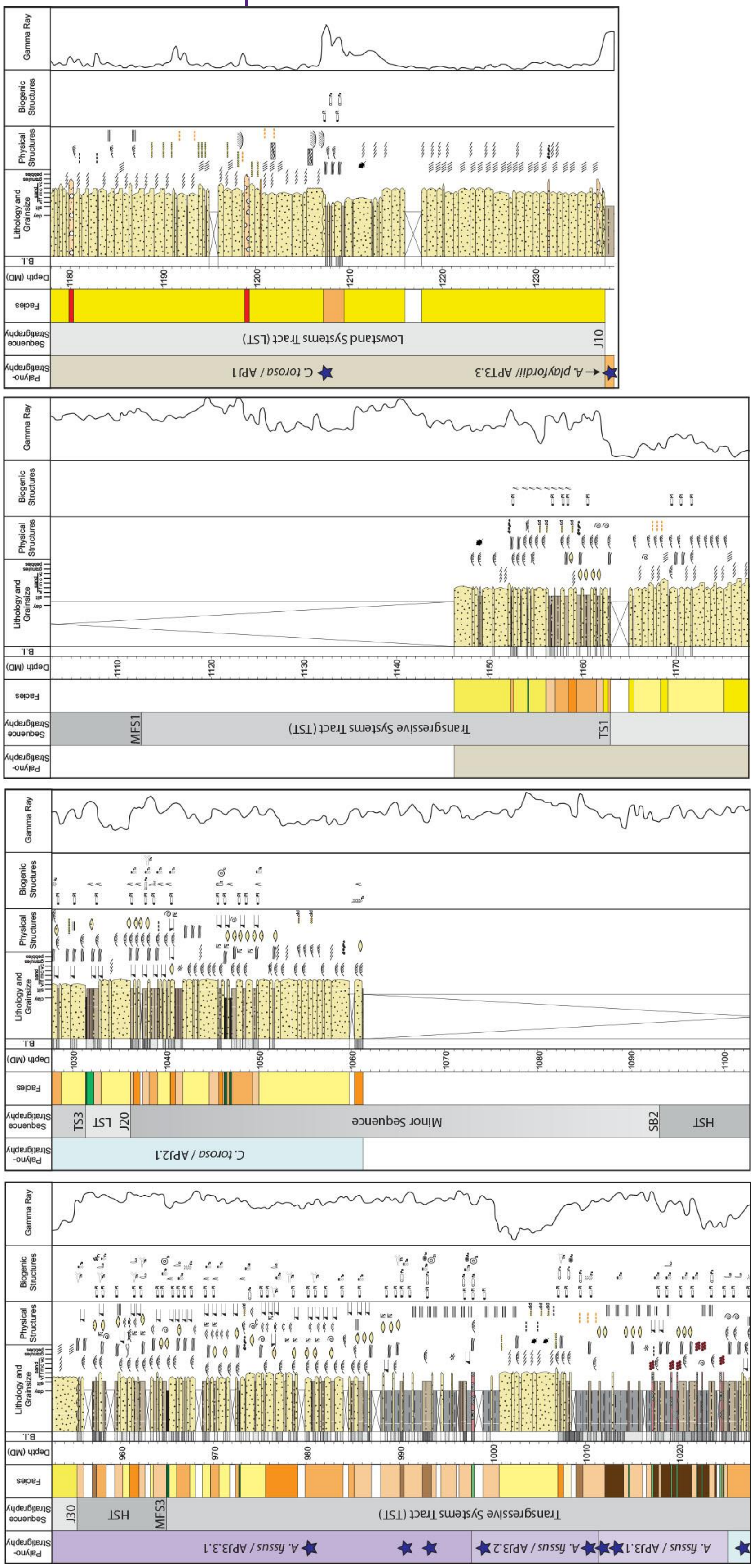

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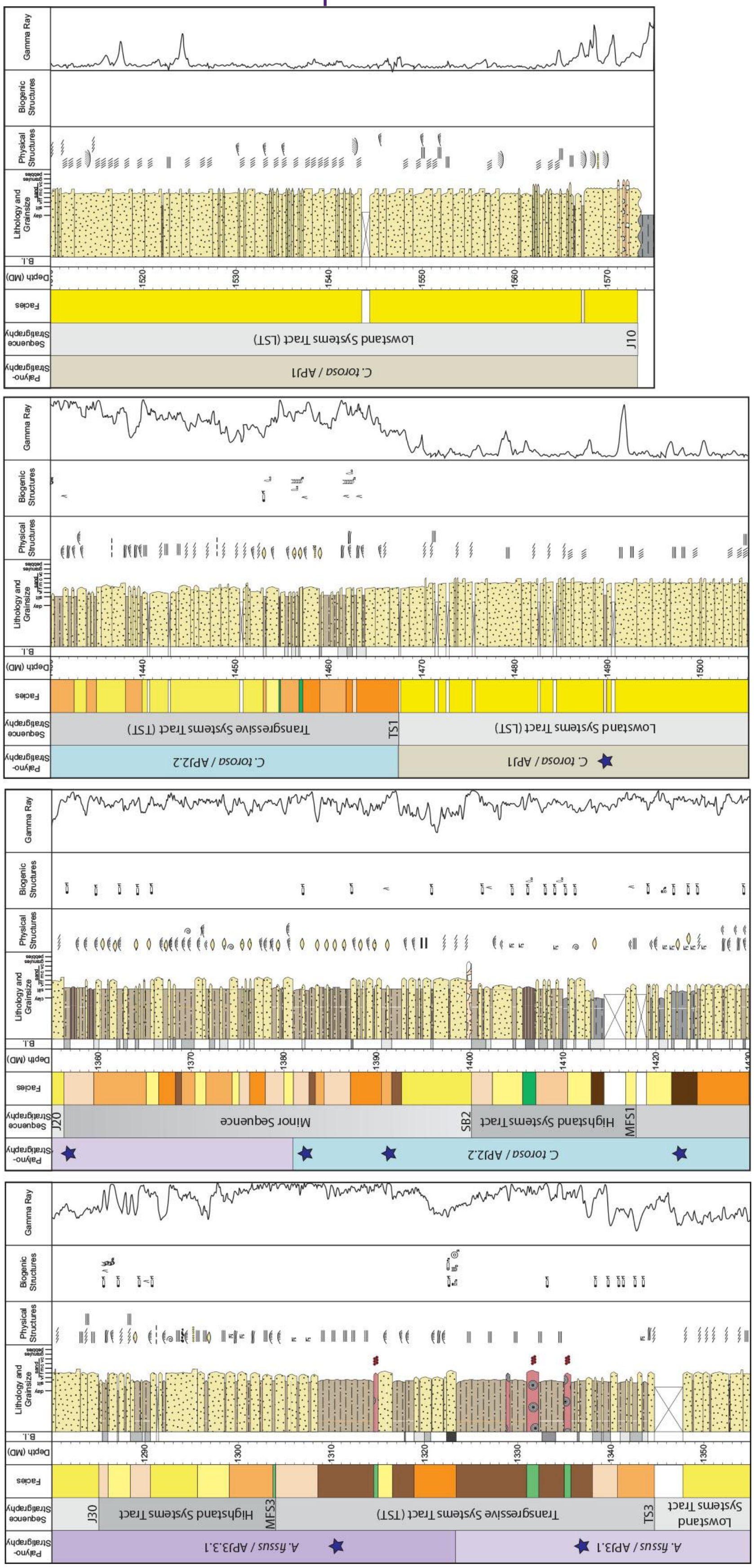

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